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FIELD TESTING THE HABITAT EVALUATION PROCEDURES FOR ALASKA

UNIVERSITY OF ALASKA

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FIELD TESTING THE  
HABITAT EVALUATION PROCEDURES  
FOR ALASKA

A  
THESIS

Presented to the Faculty of the  
University of Alaska in partial fulfillment  
of the Requirements  
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By

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Fairbanks, Alaska

December 1982

FIELD TESTING THE HABITAT EVALUATION PROCEDURES

FOR ALASKA

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### ABSTRACT

Field tests were conducted to assess the precision and accuracy of the Habitat Evaluation Procedures (USFWS). Species models tested were for spruce grouse (Canachites canadensis), red squirrel (Tamiasciurus hudsonicus), snowshoe hare (Lepus americanus), and moose (Alces alces) in mixed forest and for willow ptarmigan (Lagopus lagopus) and moose in shrub. Participants were able to precisely and accurately estimate nominal habitat characteristics structured in brief, succinct descriptions of habitat conditions. Mean ocular estimates of interval data were significantly greater and more variable than mean subsample estimates. Senescent vegetation in the Fall test increased the difference between subsample and ocular estimates in shrub . Most models did not accurately predict limiting factors. Subsample data generally produced significantly more precise habitat ratings (LHSI's) than did ocular data. Based on a comparison of LHSI's with species expert opinions, accuracy for all models was not acceptable. Overall, LHSI's were more accurate but less precise than subjective ratings.

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## INTRODUCTION

Increased development and exploitation of natural resources in Alaska is likely. The trans-Alaskan pipeline and the Dalton Highway have already occurred. Other large-scale projects that will undoubtedly occur are the Susitna dams, with associated access and transmission corridors, and the natural gas pipeline. Because of the fragile nature of the arctic and subarctic ecosystems, the consequences of any such development to wildlife will be significant and long-lasting.

It remains for biologists to provide a scientifically sound method of assessing impacts on wildlife habitat. The United States Fish and Wildlife Service (USFWS) has developed the Habitat Evaluation Procedures (HEP) to evaluate habitat within a proposed project area for its value to wildlife, determine any changes that may occur as a result of the proposed action, and specify mitigation and/or enhancement. HEP was conceived as an assessment tool for resource managers.

The Fish and Wildlife Act of 1934 (16 U.S.C. 661-666c; 48 stat. 401) and a 1958 ammendment (P.L. 85-624: 72 stat 563) were important steps in providing fish and wildlife resources consideration in the planning stages of federal water projects. These statutes authorized the USFWS, in conjunction with state fish and wildlife agencies, to investigate, analyze, and make suggestions to reduce the impact on fish and wildlife. With the passage of the National Environmental

Protection Act of 1969 (NEPA) (42 U.S.C. 4321.) this mandate was broadened to include all activities of all federal agencies. NEPA requires all federal agencies to utilize a systematic approach in their assessment activities and to

"identify and develop methods and procedures which will ensure that presently unquantified environmental. . .values may be given appropriate consideration in decision-making along with economic and technical considerations."

Man-day-use estimates had been set as the standard by which to measure effects of proposed water projects on wildlife (Senate Document 97 of the 87th Congress). Biologists felt this concept was unsuitable because it was limited in its applicability, dealt only with game species and did not really consider the resource but rather human utilization of it. In response to the inadequacy of the man-day-use approach and its apparent conflict with NEPA, Daniels and Lamaire (1974) devised a habitat evaluation system for Missouri. This system was one of the first assessments which assumed habitat quality could be described by a numerical index.

The Missouri system was adopted by the USFWS, Division of Ecological Services, which first issued HEP in 1976 (USFWS 1976). HEP was an attempt to standardize the method of impact assessment. The method required a team of experienced biologists to develop key criteria for habitat quality for each of approximately ten wildlife species or groups of species. A representative number of sites in each habitat type were rated on a scale of 0.0 (no value) to 1.0



(optimum value) for their importance to the species or groups of species. Ratings were reached by group consensus. Higher ratings reflected more suitable habitats. USFWS field form 3-1101 was used to record evaluations.

This system was criticized because it depended on subjectively determined criteria for habitat suitability. Results were difficult for other teams to duplicate and indices of habitat quality were often biased by the more persuasive team members. Professionals from other fields in which more precise procedures are used did not readily accept these results.

Such criticisms were the impetus for the development of the Missouri handbook (Flood et al 1977). This approach was designed to strengthen field assessments by providing key evaluation criteria. Handbooks standardize habitat evaluation for a particular region, and they allow a team of biologists to evaluate an assortment of habitats for species about which they may have only limited knowledge. The USFWS, in general agreement with the approach, has undertaken to produce habitat evaluation criteria handbooks for each of the ecoregions described by Bailey (1976). I was hired by the USFWS to help develop such a handbook for Alaska. In this capacity I wrote habitat requirements accounts and evaluation models for six species of birds and mammals (Konkel 1980). These species were the red squirrel, spruce grouse, willow ptarmigan, brown bear, common redpoll and Lapland longspur. The red squirrel, spruce grouse and willow ptarmigan models were tested in the present study.

The objectives of this study were as follows:

- 1.) Determine if HEP provides an accurate and precise index to the importance of key habitats to selected mammals and birds in interior Alaska.
- 2.) Compare the methods of obtaining habitat data as to their practicality and how they affect accuracy and precision of HEP models.
- 3.) Compare how different mathematical functions used to calculate habitat suitability indices affect accuracy and precision of the models.
- 4.) Examine how habitat suitability indices are effected by seasonal changes in habitat.

## STUDY AREA

Field tests were conducted at the Bonanza Creek Experimental Forest (64 degrees 45 minutes N, 148 degrees 15 minutes W) approximately 25 km (15 mi.) southwest of Fairbanks, Alaska (Figure 1). Three mixed deciduous-coniferous forest and three shrubland sites, each approximately 1 ha (2.5 ac.), were used for the field tests. Six sites were considered the maximum number that could be dealt with in the available time. Areas were selected for homogeneity of vegetative type, adequate size, accessibility and ease of movement within the site. Access to the test sites was via a dirt and gravel road at Mile 339 of the Parks Highway (Alaska Route 3) extending north to the Tanana River.

### Mixed forest

The three mixed forest sites were all very similar in their vegetative communities. Tree canopy was almost completely composed of mature white spruce (Picea glauca) and paper birch (Betula papyrifera). Occasionally an aspen (Populus tremuloides) occurred. The tallest trees reached 22.9 m (75 ft).

American green alder (Alnus crispa) was the most noticeable shrub on all mixed forest sites. This shrub regularly reached 4.6 m (15 ft) in height. Its many stems branching from a common base were relatively thick at 2.5-5.0 cm (1-2 in.) diameter at breast height (dbh). Alders grew in areas beneath large openings in the tree

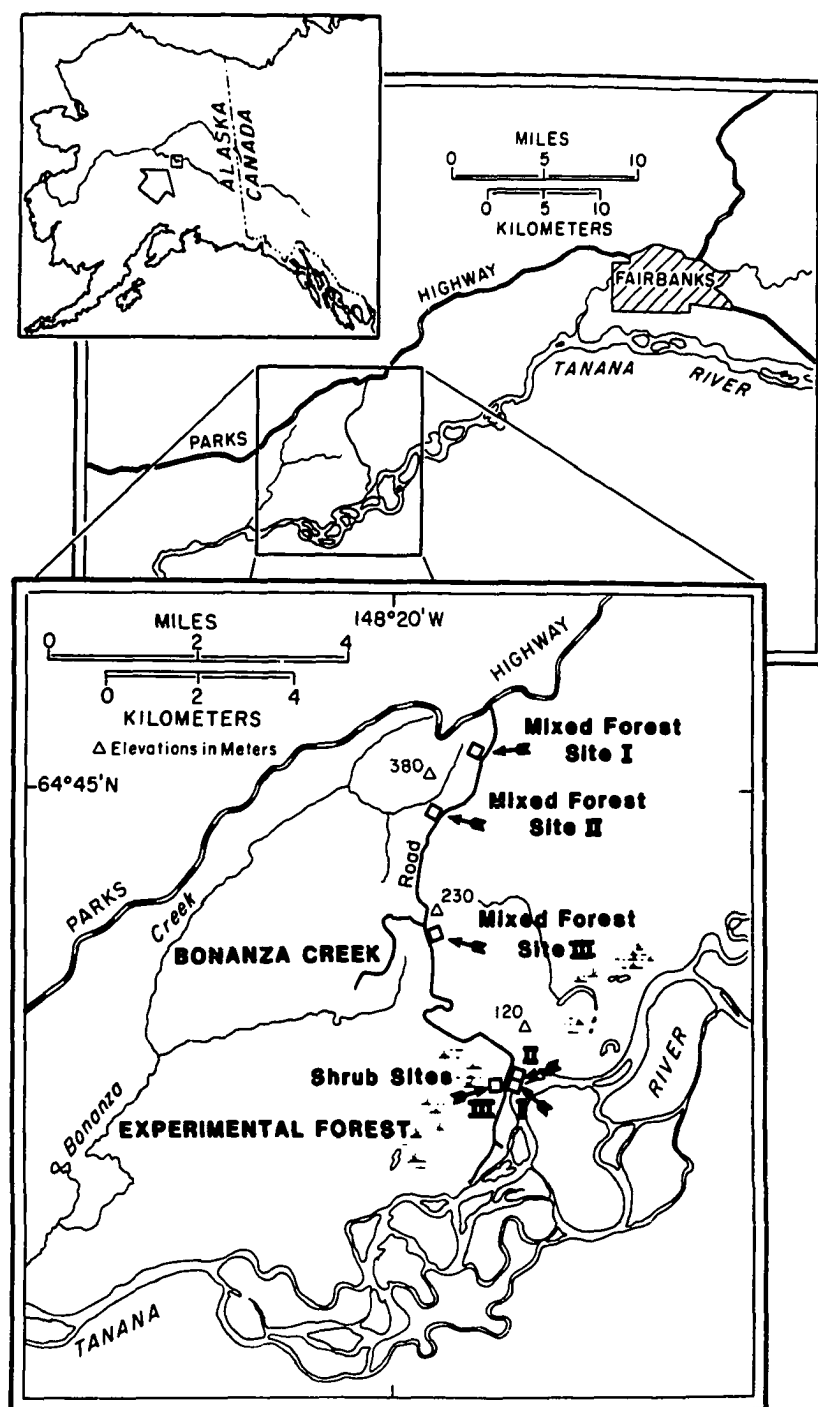


Figure 1. Bonanza Creek Experimental Forest showing sites where field tests were conducted.

canopy. Other shrubs on the study site, such as prickly rose (Rosa acicularis) and highbush cranberry (Viburnum edule) had more stems per unit area but were very slender and rarely exceeded 1.2 m (4 ft) in height.

The spotty ground cover consisted of mosses (primarily Dicranum fuscescens and Hylocomium splendens), horsetail (Equisetum arvense), lowbush cranberry (Vaccinium vitis-idaea), dwarf dogwood (Cornus canadensis) and bluejoint grass (Calamagrostis canadensis).

All three mixed forest sites had low relief and were well drained. Sites I and II sloped very slightly to the south. Site III has an easterly aspect at a slope of 10 degrees. Elevations ranged from 274 m (900 ft) above sea level (ASL) at site I to 152 m (500 ft) ASL at site III.

### Shrubland

Two tall shrub and one low shrub sites were selected for habitat evaluation. (Habitat classification follows Dyrness and Viereck (1980)). All three sites were located on the flood plain of the Tanana River (Fig. 1) at an elevation of approximately 100 m (330 ft).

Site I. This tall shrub stand was contiguous with site II. Division into two stands was based on differences in overall appearance and shrub density. Tall trees were totally lacking. Willow (Salix sp.) was the dominant shrub, but American green alder and Balsam poplar (Populus balsamifera) saplings were also common.

The stand was characterized by large open areas, many of which

exposed bare ground or a sparse moss covering. The plot was bordered on the east by a slough of the Tanana River, to the north and west by a white spruce stringer and to the south by an island of white spruce and cottonwood and the second shrub site.

Site II. This tall shrub stand had a denser and more continuous shrub canopy than did site I. Willow was the dominant shrub but balsam poplar saplings were also common, making up approximately 20% of the stand. Shrubs were also taller at this stand, ranging from 1.5 m (5 ft) to 5.5 m (18 ft). A moose enclosure erected by the Institute of Northern Forestry stands in the southern section of the area. The southern boundary lies along the Tanana River. White spruce and cottonwood stands lie to the east and west. The stand was continuous with Shrub 1 to the north.

Ground vegetation was very similar to that in site I. Horsetail (E. arvense) was by far the dominant herb. Also occurring were pyrola (Pyrola asarifolia), hooded lady tresses (Spiranthes romanzoffia), fireweed (Epilobium angustifolium), grass-of-Parnassus (Parnassia palustris), wormwood (Artemesia sp.) and yarrow (Achillea lanulosa).

Both site I and site II probably had been flooded within the last five years. During all three test periods no standing water was present on either site.

Site III. This low shrub site lies across the access road from site I and site II. An extensive sedge meadow bounded it on the north and west. A stringer of white spruce formed the eastern boundary and low shrub was predominant to the south. The site was poorly drained.

The dominant shrub vegetation was sweet gale (Myrica gale),

leatherleaf (Chamaedaphne calyculata) and low willow. American green alder and paper birch occasionally were present. Sedge tussocks (Eriophorum sp.) occurred throughout. The other sparse ground cover included bluejoint grass and cloudberry (Rubus chamaemorus)

Shrub height averaged less than 1 m (3.3 ft). The canopy was fairly continuous, approaching 75%.

## METHODS

### Test dates

Field tests were conducted during May (Spring), July (Summer), September (Fall) 1979. Tests dates within a period were arranged as close to one another as possible to guarantee that participants were rating the sites under approximately the same conditions.

### Personnel

A total of 22 biologists participated in the field testing. The University of Alaska (Fairbanks), Alaska Department of Fish and Game (Fairbanks), United States Fish and Wildlife Service (Fairbanks, Anchorage), United States Forest Service (Fairbanks), and United States Bureau of Land Management (Fairbanks) were represented. Participants were encouraged to attend more than one test period. Those that did retake the field test were allowed to partake in only one test in any given period. A total of 29 tester days were used to evaluate habitat over the three periods.

### Evaluation species

Habitat was rated for the same group of five wildlife species during the three test periods. Mixed forest sites were evaluated for moose (Alces alces), red squirrel (Tamiasciurus hudsonicus), snowshoe hare (Lepus americanus), and spruce grouse (Canachites canadensis). Evaluation species in shrub were moose and willow ptarmigan (Lagopus



lagopus).

### Testing

Prior to conducting the field tests, participants were given a short introduction to the principles of HEP and an explanation of test procedures. Each was provided with a packet of test forms and a sheet defining terms used in the test. Participants were also requested to read summaries of the habitat requirements for the evaluation species. This was done to insure that everyone was at least minimally familiar with species needs. Participants were instructed to work independently to assure statistical validity and to consider only the area within clearly marked boundaries at each site. The order of the sites visited was the same for each test.

Field testing consisted of three separate phases which were conducted in the following order: subjective rating of the habitat; ocular inventory of habitat characteristics; and subsampling of habitat characteristics.

#### Subjective rating of the habitat

The field form used for the subjective rating of the habitat is similar to Form 3-1101 that the USFWS used for early habitat assessments. Test sites are indicated across the top of the form with the evaluation species listed down the side. Sites were rated for their quality on a scale of 0.0 to 1.0.

Participants were asked to rate the habitat as a whole, based on their subjective knowledge of each species involved. Higher ratings

indicate a more attractive habitat than do lower ratings. In the May test, participants were asked to give an overall rating for the site. Following this first test I realized that some HEP models evaluated winter range as well as non-winter range. Both a summer and winter subjective rating were requested for the July and September tests to allow for a complete comparison with all HEP models.

#### Ocular inventory of habitat characteristics

In this phase of the testing the habitat was broken down into component parts. These characteristics are taken directly from the HEP handbook and they represent a list of critical habitat attributes that determine the value of a site for the five evaluation species.

On the field form used for the ocular inventory test sites are indicated across the top. The habitat characteristics to be inventoried are listed down the left side. Participants were asked to walk through an area and approximate values for each of the features.

Both ratio and nominal type data were gathered through the ocular inventory. By ratio data it is meant that the interval between possible assigned values is uniform. For example, percentages are ratio data because the interval between one and two percent is the same as between, say, 24 and 25 percent. Heights of vegetation would be considered ratio data.

Nominal data habitat characteristics were presented as discrete categories which described a range of possible conditions in a habitat. An example of such an attribute would be the moisture

regime, which was characterized as follows:

A = ground poorly drained, standing water present;  
generally underlain with permafrost

B = moist areas, usually free of standing water

C = well-drained soil, no standing water.

#### Subsampling of habitat characteristics

A modified version of the vegetative sampling scheme described by Ohmann and Ream (1971) was employed for this part of the test. Because the sampling procedure was very time consuming, test participants were asked to sample only mixed forest site II and shrub site II test sites. I sampled the subplots in the remaining four sites at the conclusion of each test period.

In each test site, ten systematically selected sample points were established. The interval between each point was 25 m (82 ft). Three sampling procedures for the tree, shrub and ground vegetation strata were conducted around each sample point.

Trees. Tree species, height, and density were determined using the point-centered quadrant method devised by Cottam and Curtiss (1956) The space around each sample was divided into four equal quadrants formed by the line of travel and a line perpendicular to it. The quadrants were numbered 1, 2, 3, 4 with the first quadrant always being to the upper right while facing in the line of travel.

The other quadrants were numbered consecutively in a clockwise manner from the first quadrant.

In each quadrant the distance from the sample point to the nearest tree was recorded as well as the species and height.

For this study a tree was defined as any individual from a typical tree species (e.g. birch, aspen) greater than 3.7m (12 ft) tall or any individual from a typical shrub species (e.g. willow, alder) greater than 6.1m (20 ft) tall.

Shrubs. Within a millacre (4 sq m) circular plot (radius=1.13m or 3.7 ft) centered at the sample point the number of stems of each shrub species was counted and average height estimated. In clumps of shrubs a stem was counted only if it branched at or below ten cm (3.9 in) from ground level. This height could be estimated by the width of a hand across the knuckles.

Total shrub and total tree canopy were individually estimated by projecting the millacre plot upward through the respective canopies and estimating how much canopy intersected this cylinder.

For this study a shrub was defined as any typical shrub species less than or equal to 6.1m (20ft) tall or any typical tree species less than or equal to 3.7m (12 ft) tall.

Ground cover. A 1 m (3.3 ft) x 1 m subplot was established in the first quadrant at each sample point. A collapsible aluminum frame was used to delineate the subplot. Each side was marked off in ten decimeters to aid in approximation of ground cover. Within this subplot various litter, ground and ground vegetation characteristics

were estimated. For this study vegetative ground cover was defined as mosses and herbs of any height, and woody plants less than or equal to 45 cm tall (18 in).

#### Other habitat data collection

Certain habitat features could be easily and accurately determined in the office and were not included in field testing. Size and external edge of stand, distance to marsh, and interspersions with wetlands were determined from an aerial photograph of the study area. Elevation above sea level was determined from a U.S. Geological Survey topographical map. The Institute of Northern Forestry provided data on snow depth for the study areas.

#### Species expert ratings

Biologists with extensive knowledge of one or more of the five evaluation species rated the test sites from 0.0 to 1.0. These species experts gave both a summer and a winter rating. Expert ratings were the basis for assessing the accuracy of the HEP system. At least two biologists were asked to rate habitat for each species. Unfortunately, only one expert was available to rate habitat for three of the species. Drs. Jerry Wolff (INF) and William Gasaway (ADFG) and Steve Dubois (ADFG) rated the sites for moose. Dr. Wolff and Ms. Fran Nodler rated the sites for red squirrel. Dr. Wolff also acted as the snowshoe hare expert. Dr. Robert Weeden (UAF) rated the sites for willow ptarmigan and spruce grouse.

### Determination of Habitat Suitability Indices

The Terrestrial Habitat Evaluation Criteria Handbook--Alaska (Konkel 1980) developed by USFWS served as the basis for site evaluations. The handbook contains a narrative in the form of a literature review detailing habitat requirements of selected species of mammals and birds. Each species account devotes a section to distribution and habitats used and specific needs for food, water, cover, reproduction, interspersions and special considerations.

In addition, for every vegetative type in which a species is found the handbook provides a set of transformation curves and bar graphs which is the mechanistic means of evaluation. Graphs used in the evaluation of mixed coniferous-deciduous forest for red squirrel are given as an example (Figure 2). Evaluations are hierarchical in that suitability indices are assigned first to individual habitat variables, then to habitat components (e.g. food, interspersions, winter range) and finally to the habitat as a whole. "Suitability" cannot actually be measured for a particular variable since it is an index and therefore cannot be expressed in quantified units. It can be thought of as the estimated or measured value of a habitat characteristic compared to the optimal value or range of values for a species. The relationship between suitability and a given parameter is assumed to be independent of other variables affecting suitability (USFWS 1980a; 1980b; 1981).

The graphs, whose general shape and range of values is derived from the literature, relate various measurements of a habitat

RED SQUIRREL  
MIXED CONIFEROUS-DECIDUOUS FOREST

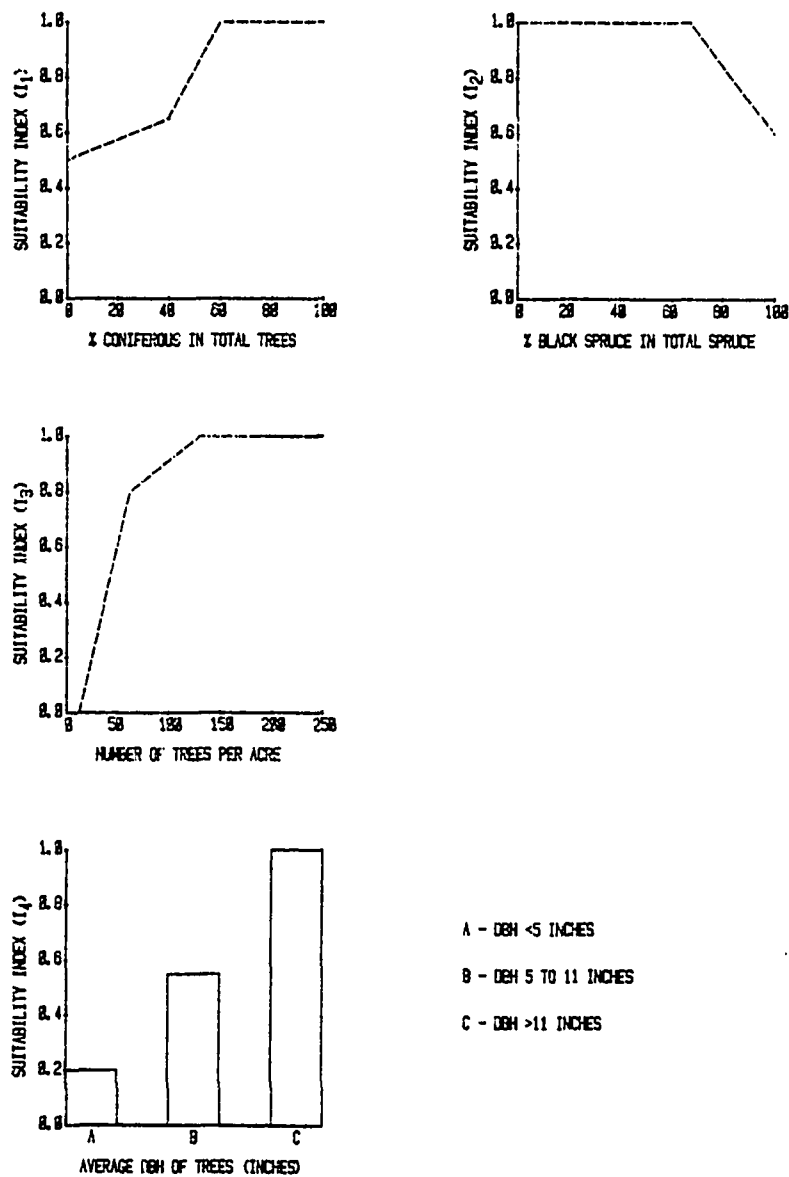


Figure 2. Transformation curves and bar graphs used to interpolate suitability indices from measurements of habitat characteristics in the red squirrel evaluation model for mixed forest. Examples are from the Terrestrial Habitat Evaluation Criteria Handbook- Alaska (Konkel 1980).

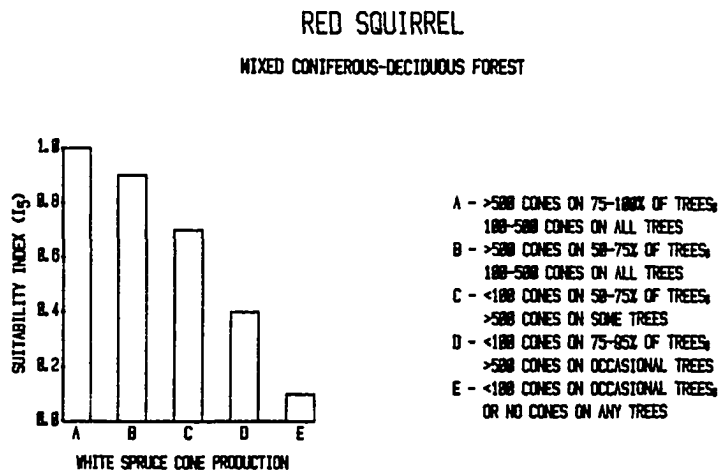


Figure 2. (continued)



characteristic (x-axis) to a suitability index (y-axis) ranging from 0.0 to 1.0. Suitability indices are interpolated directly from transformation curves and bar graphs for each variable. These biotic and abiotic variables have been documented as important factors for the survival of a species in a particular vegetative type.

Suitability indices from a combination of variables are used in a mathematical function to derive a value ( $X_n$ ) for each habitat component (Figure 3). The lowest  $X_n$  represents the limiting factor for the species and is assigned as the Habitat Suitability Index (HSI) for the species in question. The HSI indicates the capacity of a habitat to support a species. The optimum habitat is assigned an HSI of 1.0.

Two mathematical functions were used to calculate HSI's. The multiplicative mean function arrived at an HSI simply by multiplying suitability indices:

$$X_n = I_1 \times I_2 \times I_3.$$

The geometric mean multiplies the indices and then takes the appropriate root of the product:

$$X_n = (I_1 \times I_2 \times I_3)^{1/3}.$$

An example will help clarify this entire process. To evaluate mixed coniferous-deciduous forest for red squirrel five habitat characteristics must be inventoried — % coniferous trees in total trees, % black spruce in total spruce, numbers of trees per acre,

## HABITAT SUITABILITY INDEX

## Red Squirrel in Mixed Coniferous-Deciduous Forest

$$\text{Food Value } (X_1) = I_1 \times I_2 \times I_3 \times I_4 \times I_5$$

Where:  $I_1$  = Suitability Index of % coniferous in total trees

$I_2$  = SI of % black spruce in total spruce

$I_3$  = SI of number of trees per acre

$I_4$  = SI of average DBH of trees (inches)

$I_5$  = SI of white spruce cone production

$$\text{Cover Value } (X_2) = I_3 \times I_4$$

Where:  $I_3$  = SI of number of trees per acre

$I_4$  = SI of average DBH of trees (inches)

$$\text{Reproductive Value } (X_3) = I_1 \times I_2 \times I_3 \times I_4 \times I_5$$

Where:  $I_1$  = SI of % coniferous in total trees

$I_2$  = SI of % black spruce in total spruce

$I_3$  = SI of number of trees per acre

$I_4$  = SI of average DBH of trees (inches)

$I_5$  = SI of white spruce cone production

The Habitat Suitability Index is the lowest  $X_n$  value.

Figure 3. Formulae used in determining Habitat Suitability Indices (HSI's) for mixed forest in the red squirrel evaluation model. Example is from the Terrestrial Habitat Evaluation Criteria Handbook-Alaska (Konkel 1980).

average diameter at breast height (dbh) of trees, and white spruce cone production. At a hypothetical site 50% of the total trees were coniferous, none of which were black spruce. The area had 100 trees per acre with an average dbh of 20 cm (8 in). White spruce had a bumper crop of cones with all trees bearing more than 500 cones.

Suitability indices for each of these variables are derived from the set of evaluation graphs shown in Figure 2. For instance, for the first variable the suitability index (I1) of 50% coniferous trees in total trees is 0.80. Similarly, I2 (0% black spruce in total spruce) = 1.00; I3 (100 trees per acre) = 0.90; I4 (average dbh of 20 cm (8 in)) = 0.60; I5 (> 500 cones on all white spruce trees) = 1.00.

The Food Value (X1) involves the suitability indices for all five habitat variables. Models in the handbook used the multiplicative mean for calculations:

$$\begin{aligned}\text{Food Value (X1)} &= I1 \times I2 \times I3 \times I4 \times I5 \\ &= 0.80 \times 1.00 \times 0.90 \times 0.60 \times 1.00 \\ &= 0.43.\end{aligned}$$

The corresponding value derived from the geometric mean is:

$$\begin{aligned}\text{Food Value (X1)} &= (I1 \times I2 \times I3 \times I4 \times I5)^{1/5} \\ &= (0.80 \times 1.00 \times 0.90 \times 0.60 \times 1.00)^{1/5} \\ &= 0.85.\end{aligned}$$

Using the same procedures:

Cover Value (X2) = 0.54 (multiplicative mean)

= 0.73 (geometric mean)

Reproduction value (X3) = 0.43 (multiplicative value)

= 0.85 (geometric mean).

The habitat component (Xn) with the lowest value is considered the limiting factor. In this example, food and reproduction are limiting for red squirrel in mixed coniferous-deciduous forest when the HSI's were calculated by the multiplicative mean. Cover was limiting when the geometric mean was used. The Limiting Habitat Suitability Index (LHSI) was 0.43 for the multiplicative mean and 0.73 for the geometric mean.

HSI's were determined by the USFWS in Anchorage, Alaska, using both ocular and subsample estimates of habitat characteristics.

## RESULTS AND DISCUSSION

Results from the field testing were analyzed to determine the accuracy and repeatability (precision) of the HEP process in rating habitat quality. Additionally, the analysis examines how precision and accuracy are affected by the following:

- 1.) the method used to inventory the habitat characteristics (ocular and subsample);
- 2.) the mathematical treatment used to determine HSI's (multiplicative mean and geometric mean);
- 3.) the habitat type being evaluated.
- 4.) the season in which the evaluation occurred;

Most results are presented both by season and for all seasons combined. The order in which the results are presented reflects the hierarchy of the HEP system. Individual habitat characteristics are examined first. No statistical comparison of inventory methods for nominal data was made since these characteristics were estimated by the ocular method only (see page 22 for an explanation of nominal and interval data). Relative frequency of responses to each nominal category gives an indication of the precision associated with rating each of these variables. Interval data habitat characteristics were inventoried by both the ocular and subsample procedure. A paired t-test was performed on pairs of ocular and subsample estimates of each characteristic. Results from this test show statistical differences in values of variables due to inventory method. All statistics were tested for significance at  $p = .05$ .

Estimates of habitat characteristic values determine suitability indices which are interpolated directly from transformation curves or bar graphs for each variable. A suitability index gives an indication of how well the habitat provides a variable in a quantity and/or quality necessary for a species survival. Indices are combined by a mathematical function (multiplicative mean or geometric mean) to derive a habitat suitability index (HSI) for each of several habitat components (e.g. food, cover, interspersions). See page 29 for an explanation of the two mathematical functions. The habitat component with the lowest HSI is considered to be the limiting factor for the population of each species being evaluated. Limiting factors were examined to determine the extent of agreement between findings of test participants and if the HEP system accurately described what is limiting to a species in a particular vegetative type. Accuracy of limiting factors was determined by comparing results with findings in the literature and opinions of species experts.

The next phase of analysis dealt with the HSI values of the limiting factors. I termed these values the limiting habitat suitability indices (LHSI's). Differences between LHSI's derived from ocular data and LHSI's derived from subsample data were tested for significance in a one-way analysis of variance. Similarly, LHSI's calculated by a multiplicative mean and a geometric mean were analyzed for significant differences due to the mathematical function used in calculating HSI's.

The last section deals with the accuracy of HEP in determining habitat value. Species expert ratings are used as the criteria by

which the system is judged. A t-test was performed to see if the expert rating came from the same population as the LHSI's. Finally, the mean absolute difference between LHSI's and expert ratings are graphically displayed and examined.

#### Individual habitat characteristics

##### Nominal data habitat characteristics

Seasonal responses of the nominal data habitat characteristics for mixed forest are given in Table 1.

Participants in all tests were able to agree fairly well on the moisture regime, stand class and condition of white spruce cone crop. Responses were accurate as well as precise. The well formed white spruce and birch stands are ecologically the product of a well-drained environment. Cored white spruce averaged 77 years old and birch averaged 64 years. The moisture regime and stand class characteristics present a range of possible habitat conditions that are short, descriptive and sufficiently different to offer a clear-cut selection of responses. On the other hand, the possible responses to the white spruce cone crop parameter are confusing. The general agreement of participants can probably be explained by the poor cone crop at Bonanza Creek in the summer of 1979. John Zasada (pers. comm.) of the Institute of Northern Forestry rated the crop as poor, which corresponds to category D. It is uncertain if the responses would be as accurate or as precise in years of moderate or excellent cone production.

Table 1. Seasonal number and relative frequency (in parenthesis) of evaluator response to categories of habitat characteristics in mixed forest. These categories of habitat characteristics are considered nominal data.

Habitat Characteristics	May	July	September	Overall
<u>Moisture regime</u>				
A)Very wet areas				
B)Moist areas			1(0.09)	1(0.03)
C)Well-drained areas	13(1.00)	6(1.00)	10(0.91)	29(0.97)
<u>Interspersion value</u>				
A)Shrubs 3-8 ft high isolated	3(0.24)			3(0.10)
B)Shrubs 3-8 ft high scattered	5(0.38)	6(1.00)	9(0.82)	20(0.67)
C)Shrubs 3-8 ft high dominant	5(0.38)		2(0.18)	7(0.23)
<u>Average size of openings</u>				
A)20-30 ft across	5(0.38)	2(0.33)	4(0.36)	11(0.37)
B)15-20 ft across	3(0.24)	2(0.33)	2(0.18)	7(0.23)
C)30-40 ft across			3(0.30)	3(0.10)
D)<15 ft or >40 ft across	5(0.38)	2(0.33)	2(0.18)	9(0.30)
<u>Stand class</u>				
A)<25 years old				1(0.03)
B)25-50 years old	1(0.08)			1(0.03)
C)>50 years old	12(0.92)	6(1.00)	11(1.00)	29(0.97)
<u>Spruce cone production</u>				
A)500 or more cones on 75-100% of trees; 100-500 cones on all trees		1(0.17)		1(0.03)
B)500 or more cones on 50-75% of trees; 100-500 cones on all trees				
C)<100 cones on 50-75% of trees;500 or more on some trees				
D)<100 cones on 75-95% of trees:500 or more cones on occasional trees	2(0.16)	1(0.17)	2(0.18)	5(0.17)
E)<100 cones on occasional trees; or no cones on any trees	11(0.84)	4(0.67)	9(0.82)	24(0.80)



Ambiguous choices can also account for the lack of precision in the responses for the average size of openings characteristic. It is difficult to judge what constitutes an opening in a mixed forest stand, and even more difficult to assign a definite size to one. It is also unreasonable to assume that the openings would all fall into the same size range.

Responses to the interspersion parameter exhibited a high degree of precision for the July and September tests, but were variable for the May test. This difference could be attributed to the fact that leaves on the shrubs had not emerged as of the May test. As a result, participants were not given a clear representation of the shrub strata.

Participants showed little agreement in responses for the shrub habitat characteristics (Table 2). As in mixed forest, the interspersion value and average size of openings parameter showed little or no precision of responses. This indicates that these parameters should be restructured to present a more refined range of choice for the evaluator. Responses to the moisture regime characteristic, however, were tightly grouped in mixed forest. Since the lack of precision does not appear to be seasonal, the difference is probably attributed to misunderstanding on the part of the participants. The shrub stand is on the flood plain of the Tanana River and is subject to occasional flooding. A low wet area adjacent to this stand had standing water in it during the May and July tests. Some participants may have considered this lower and wetter area as part of the test site, while others considered only the drier area

Table 2. Seasonal number and relative frequency (in parenthesis) of evaluator responses to categories of habitat characteristics in shrub. These categories of habitat characteristics are considered nominal data.

Habitat Characteristics	May	July	September	Overall
<u>Moisture regime</u>				
A)Very wet areas	5(0.24)	3(0.17)		8(0.13)
B)Moist areas	8(0.38)	4(0.22)	2(0.08)	14(0.23)
C)Well-drained areas	8(0.38)	11(0.61)	20(0.92)	39(0.64)
<u>Interspersion value</u>				
A)Shrubs 3-8 ft high isolated	4(0.24)	4(0.22)	12(0.36)	20(0.29)
B)Shrubs 3-8 ft high scattered	7(0.41)	14(0.78)	21(0.64)	42(0.62)
C)Shrubs 3-8 ft high dominant	6(0.35)			6(0.09)
<u>Average size of openings</u>				
A)20-30 ft across	10(0.50)	4(0.22)	10(0.33)	24(0.35)
B)15-20 ft across	7(0.35)	5(0.28)	7(0.24)	19(0.28)
C)30-40 ft across		4(0.22)	9(0.30)	13(0.19)
D)<15 ft or >40 ft across	3(0.15)	5(0.28)	4(0.13)	12(0.18)

within the actual boundaries.

### Interval data habitat characteristics

Mixed forest Descriptive statistics are given for each ratio data habitat characteristic used in the species models (Appendices 1-4). For nearly every case the mean ocular estimate is greater than the mean subsample estimate. Standard deviation and coefficient of variation follow this same trend.

Differences between ocular and subsample estimates of habitat characteristics were analyzed using the Statistical Package for the Social Sciences (SPSS) paired t-test computer program. This procedure tests the null hypothesis that the difference between sample means of the two methods equals zero. The conclusions are equivalent to those from a two-way analysis of variance (Sokal and Rohlf 1969). All test dates were included to show seasonal variation.

The five habitat characteristics which showed no significant difference between means for the two inventory methods were % spruce and birch, % Populus, % black spruce, shrub and sapling height, and % berry-producing plants. Inspection of the mixed forest vegetation community indicates that values for these habitat characteristics should be apparent--either because they account for a major or negligible proportion of their respective stratum, or were fairly uniform and easily measured. The tree canopy is composed almost entirely of white spruce and birch; there is virtually no Populus or black spruce. Likewise, there is a very low percentage of berry-producing plants in the ground cover. The shrub layer is

composed predominantly of alder which is relatively even-aged and of regular height (2.4-3.7m).

Eight of the sixteen habitat characteristics in mixed forest showed consistent difference in the inventory method for all test dates. Participants were able to give equal estimates for both methods for the percent spruce and birch parameter but not for the percent spruce or percent coniferous characteristics. (Statistics for these two habitat characteristics are identical since Picea was the only coniferous genus on the test site.)

Mean estimates for the two methods differed in the three shrub canopy characteristics. This difference might be explained by the difficulty in estimating canopy coverage in any stratum. For tree and ground cover there is a clear view of the stratum by either looking straight up or down, respectively. But for estimating shrub canopy an individual is often right in the midst of the stratum and cannot get an unobstructed view.

Results shown in Table 3 suggest that participants could not estimate ground cover accurately. The mean ocular and subsample estimates of the percentage herbaceous vegetative ground cover and height of ground vegetation in openings habitat characteristics were consistently different. This can partly be explained by the technique used to sample ground cover. At each sample point a square meter plot was established and ground cover estimated. By defining a small area in which to judge coverage, estimations are likely to be more accurate, since the area is only a meter square, and more precise since all participants are looking at the same area. All habitat

Table 3. Seasonal results from a paired t-test which tested the equality of paired estimates of habitat characteristics obtained using ocular and subsample data. Results are based on pooled estimates of variance. Asterisks indicate a significant difference at  $p=.05$ .

Habitat characteristic	May (n=8)	July (n=6)	September (n=11)
<b>Mixed forest</b>			
% Spruce and birch	-1.58	-2.01	1.87
% Populus	0.00	0.00	1.16
% Spruce	6.85 *	12.17 *	21.13 *
% Coniferous	6.85 *	12.17 *	21.13 *
% Black spruce	0.54	0.72	1.74
% Tree canopy	1.85	1.93	2.20
Trees per acre	10.17 *	5.80 *	3.01 *
Height of trees	2.90	6.06 *	3.69 *
% Shrub and sapling canopy	3.78 *	3.49 *	5.86 *
% Shrub and sapling canopy (< .9 m)	4.23 *	3.47 *	6.59 *
% Shrub and sapling canopy (> .9 m)	3.89 *	3.57 *	6.08 *
Shrub and sapling height	0.73	0.89	2.33
% Ground cover	2.17	3.11	4.76 *
% Berry-producing plants	1.42	2.80	0.51
% Herbaceous ground cover	2.47 *	3.68 *	3.09 *
Height of ground cover in openings	8.62 *	8.56 *	4.10 *
<b>Shrub</b>			
% Alder	3.67 *	8.67 *	3.73 *
% Willow	0.32	0.50	3.27 *
% Shrub canopy	2.19	1.97	3.81 *
% Shrub canopy (< 3.1 m)	2.34	1.41	4.63 *
% Shrub height	3.58 *	0.20	0.09
% Forbs	1.55	0.19	3.60 *
% Bryophytes and graminoids	1.27	0.54	8.04 *
Height of ground vegetation	1.43	2.69	0.65

characteristics associated with ground vegetation had means and standard deviations which were greater for the ocular method than the subsample method.

Shrub Descriptive statistics followed the same trend in the shrub habitat (Appendices 5-8) as in mixed forest.

Results from the paired t-tests for the shrub habitat (Table 3) revealed only one significant difference for all test dates (% alder). This consistency might arise from the simple vegetative community on the test site. There were no trees present, and shrubs were dominated by willow, with some poplar and alder present. Ground cover was dominated by horsetail. In addition to the simple species composition the physical structure of the community was uniform. The shrubs were straight and unbranching, ranging in height from 2.4-4.5m. The horsetail appeared as a continuous green blanket, changing only in height as the growing season progressed.

Seasonal variation The September field test produced the greatest number of habitat characteristics exhibiting a difference in the two inventories (Table 3). This was true in both habitat types, but especially noticeable in shrub habitat. In the mixed forest type, 11 of 16 habitat characteristics showed a significant difference. Results were significantly different for six of the eight habitat characteristics in the shrub type. The large number of parameters showing differences in inventory methods in September can be largely attributed to senescent vegetation. By this time of year (late September-early October) at Bonanza Creek, trees and shrubs were well

into shedding their leaves. Ground vegetation was dying back. The uniform green covering of horsetail on the shrub test site had changed to a wilted mat of greenish-brown. Distinguishing between dead and dying vegetation no doubt greatly added to variation in participants' estimates.

Results from the May and July tests were similar. The habitat characteristics which showed a difference in the two methods were nearly the same for both tests in mixed forest. In shrub, the ocular and subsample estimates were different for only one parameter (% alder) in July and only two habitat characteristics showed differences in May.

These results suggest guidelines for which method(s) to use to inventory critical habitat characteristics. Time needed to complete the inventory of an area will probably be a critical factor in any habitat evaluation scheme. The subsample method is a time-consuming but more statistically valid approach than the ocular method. The time needed for a subsample inventory ranged from 72 minutes to 190 minutes. Ocular estimates took between ten and 25 minutes to complete. Therefore, to minimize the time necessary for an inventory, habitat characteristics which consistently show no significant difference between the two methods of inventory should be estimated ocularly. Conversely, those habitat characteristics with ocular estimates consistently different from the subsample estimates should be sampled by subsampling estimation.

The resultant combination of subsampled and ocularly estimated

habitat characteristics will depend to a large degree on both the habitat type and season in which the inventory takes place. A preliminary survey of an area should give the evaluator an idea of which habitat characteristics can be easily and accurately estimated by the ocular method. These will include those habitat characteristics which appear to have either a negligible or very dominant effect on the community (e.g. the percent Populus or percent spruce and birch habitat characteristics referred to earlier).

Seasonality will have a strong influence on which variables will be estimated by one method and which by the other. Evaluations done very early (before emergence) or late in the season will probably necessitate more subsampling; vigorous vegetation is more accurately ocularly measured than senescent vegetation. Table 3 suggests that any time from just after emergence to the onset of senescence is the optimal time for evaluations at Bonanza Creek. This corresponds roughly to a four month period from the third week in May to the third week in September.

Test participants had varied backgrounds in field biology. Few had substantial training in sampling vegetation. Undoubtedly this lack of experience greatly increased the variability in estimates of habitat characteristics. Biologists specially trained in the sampling techniques used to estimate habitat characteristics could greatly reduce the variability of those estimates.

#### Limiting factors

The species models assign HSI values to critical life



requirements such as food, water, interspersions, cover and reproduction. The life requisite with the lowest assigned value is considered the limiting factor for the species in that particular habitat. The limiting life requisite HSI value is referred to as the Limiting Habitat Suitability Index (LHSI). The LHSI is the value assigned to the habitat.

Each participant's ocular and subsample estimates of habitat characteristics were used to determine life requisite HSI values for spruce grouse, red squirrel, snowshoe hare and moose in mixed forest, and for willow ptarmigan and moose in shrub. In addition, winter range values were determined for spruce grouse and moose in mixed forest and willow ptarmigan in shrub. HSI's and winter range values were calculated using both a multiplicative mean and a geometric mean mathematical function. For a given species then, each participant's estimates generated four limiting life requisites (and four LHSI's):

- 1.) using ocular data in the multiplicative mean function;
- 2.) using ocular data in the geometric mean function;
- 3.) using subsample data in the multiplicative mean function;
- 4.) using subsample data in the geometric mean function.

Spruce grouse Food was the limiting life requisite almost exclusively for spruce grouse in the models using a geometric mean (Table 4). The multiplicative model indicated slightly different life requisites were limiting for the ocular and subsampled estimates. The ocular data predominantly produced limiting values for the cover life requisite. The subsample data generated values that indicate food was

Table 4. Limiting life requisites for spruce grouse which yielded the lowest habitat suitability indices in mixed forest. HSI's were calculated using both a geometric mean and a multiplicative mean on data collected both ocularly and by subsample.

<u>Participant</u>	<u>Ocular</u>		<u>Subsample</u>	
	Multiplicative	Geometric	Multiplicative	Geometric
<u>May</u>				
1	Cover	Food	Food	Food
2	Cover	Food	Food	Food
3	Cover	Food	Food	Food
4	Cover	Food	Cover	Food
5	Food	Food	Food	Food
6	Cover	Food	Food	Food
7	Cover	Food	Food	Food
8	Cover	Food	Cover	Food
<u>July</u>				
9	Reproduction	Food	Food	Food
10	Cover	Food	Cover	Food
11	Cover	Food	Cover	Food
12	Cover	Food	Cover	Food
13	Cover	Food	Reproduction	Food
14	Cover	Food	Cover	Food
<u>September</u>				
15	Cover	Food	Food	Food
16	Cover	Food	Cover	Food
17	Cover	Food	Cover	Food
18	Cover	Food	Cover	Food
19	Cover	Food	Cover	Food
20	Cover	Food	Cover	Food
21	Food	Food	Cover	Food
22	Cover	Food	Cover	Food
23	Cover	Food	Cover	Cover
24	Cover	Food	Cover	Food
25	Food	Food	Cover	Food

the limiting factor in May and cover was limiting in July and September.

This last model -- using subsample data with the multiplicative mean -- comes closest to representing the situation at Bonanza Creek. Non-winter habitat requirements for the spruce grouse center on food and cover, especially for brood protection. Mixed forests of white spruce and birch with understories of blueberries (Vaccinium uliginosum), cranberry (V. vitis-idaea), spiraea (Spiraea sp.), and grasses are preferred habitats (Ellison 1968 cited in Johnsgard 1973). Blueberries and cranberries are probably the most important features of good summer habitat. Besides providing good spring, summer, and fall foods, if these two plants are abundant the vegetative structure of the understory is conducive to display, brood rearing and even nesting (Ellison pers. comm.). An understory with alder is much less favored but can still attract broods and molting adults (Ellison 1971). This latter case is the situation at the Bonanza Creek sites. Blueberries and cranberries were not in abundance; alders were the dominant understory component. Lack of blueberries and cranberries suggest that cover and food were limiting to spruce grouse densities.

Snowshoe hare Snowshoe hare non-winter habitat preference appears to depend mainly on cover density and availability of food (Wolff 1977, 1978; Conroy et al 1979). Protection from avian predation is provided by heavy cover about 3 m above the ground. Ground cover (< 1 m) offers concealment from terrestrial predators.

Alders up to 4.5 m growing in openings and low shrubs dispersed throughout the site provided sufficient understory cover. Herbaceous ground cover was sparse and spotty. In mixed forest habitat food availability is probably limiting to hares only in the summer when the diet is primarily herbaceous. At other times cover is likely to be the limiting factor. The snowshoe hare model produced HSI's which were predominantly lowest and limiting for food, regardless of data set or method used to calculate these ratings (Table 5). Therefore, only the results from the Summer test realistically reflected what was limiting to hares at Bonanza Creek.

Red squirrel Without exception, HSI's for both food and cover were calculated to be equal and limiting. The correspondence between food and cover LHSI's is due to both factors being determined by the same five habitat characteristics. Layne (1954) found sufficient food to be the primary habitat requirement of red squirrels. In interior Alaska forests, white spruce seeds are the heavily preferred food item (Dice 1921; Murie 1927; Brink and Dean 1966). Red squirrels emigrate from white spruce habitat in times of white spruce cone failure (Brink 1966; Smith 1966). Since the white spruce cone crop was poor in 1978 and 1979 (Zasada pers. comm.) it follows that food was the limiting factor to squirrel densities, and in that respect the model was accurate. However, the model also indicated that reproduction was equally limiting, but this does not appear to be the case.

Moose In general, the multiplicatively calculated HSI's

Table 5. Limiting life requisites for snowshoe hare which yielded the lowest habitat suitability indices in mixed forest. HSI's were calculated using both a geometric mean and a multiplicative mean on data collected both ocularly and by subsample.

Participant	<u>Ocular</u>		<u>Subsample</u>	
	Multiplicative	Geometric	Multiplicative	Geometric
<u>May</u>				
1	Food	Food	Food	Food
2	Food	Food	Food	Food
3	Food	Food	Food	Food
4	Food	Food	Food	Food
5	Food	Food	Food	Food
6	Food	Food	Food	Food
7	CR *	Food	Food	Food
8	Food	Food	CR *	CR *
<u>July</u>				
9	CR *	CR *	Food	Food
10	Food	Food	Food	Food
11	Food	Food	Food	Food
12	Food	Food	Food	Food
13	FCR	Food	Food	Food
14	Food	Food	Food	Food
<u>September</u>				
15	Food	Food	Food	Food
16	Food	Food	Food	Food
17	Food	Food	Food	Food
18	Food	Food	Food	Food
19	CR *	Food	Food	Food
20	CR *	CR *	Food	Food
21	Food	Food	Food	Food
22	Food	Food	Food	Food
23	Food	FCR	CR *	Food
24	Food	Food	Food	Food
25	Food	Food	Food	Food
* Cover and reproduction				

were lowest and limiting for food; the geometric mean was lowest for reproduction (Table 6). Moose biologists Bill Gasaway and Steve DuBois from the Alaska Department of Fish and Game (pers. comm.) partially agree with the results from the multiplicative model. It is their experience that both food and cover are limiting to moose in mixed forest throughout the year. In a mature mixed forest, moose densities will never be high unless moose are forced into lowland situations by deep snow. Food species are probably not abundant nor would they be in the height range (1-4.5m) upon which moose usually feed. The high tree canopy and minimal shrub canopy offer little in the way of cover for a moose. They did not consider reproduction, which was indicated as the limiting factor by the geometric model, to be a consideration in the degree to which moose utilized mixed forest.

In shrub, Gasaway and DuBois point to interspersed as the limiting factor. Food is plentiful and accessible. Cover is not great within the stand itself, but most moose observed in such pure stands of shrub have been near bordering forest. Interspersed is especially important from March to June. In early March, moose seek low areas of minimal snow accumulation to wait out the winter. To those utilizing shrub areas, stringers of spruce offer critical cover. This is especially true for cows with calves.

Results from the models do not agree with this assessment (Table 7). Reproduction was the exclusive limiting factor based on the geometric mean. The results from the multiplicative model show little consistency. Interspersed was the most prominent limiting factor in

Table 6. Limiting life requisites for moose which yielded the lowest habitat suitability indices in mixed forest. HSI's were calculated using both a geometric mean and a multiplicative mean on data collected both ocularly and by subsample.

<u>Participant</u>	<u>Ocular</u>		<u>Subsample</u>	
	Multiplicative	Geometric	Multiplicative	Geometric
<hr/>				
May				
1	Food	Reproduction	Food	Reproduction
2	Food	Food	Food	Reproduction
3	Food	Reproduction	Food	Reproduction
4	Food	Reproduction	Food	Reproduction
5	Food	Reproduction	Food	Reproduction
6	Food	Reproduction	Food	Reproduction
7	FR *	Reproduction	Food	Food
8	Food	Reproduction	Food	Reproduction
July				
9	Reproduction	Reproduction	Food	Reproduction
10	Food	Reproduction	Food	Reproduction
11	Food	Reproduction	Food	Reproduction
12	Food	Reproduction	Food	Reproduction
13	Food	Reproduction	Food	Reproduction
14	Food	Reproduction	Food	Reproduction
September				
15	Food	Reproduction	Food	Reproduction
16	Food	Reproduction	Food	Reproduction
17	Food	Reproduction	Food	Reproduction
18	Food	Reproduction	Food	Reproduction
19	Food	Reproduction	Food	Reproduction
20	Reproduction	Reproduction	Food	Reproduction
21	Food	Reproduction	Food	Reproduction
22	Food	Reproduction	Food	Reproduction
23	Food	Reproduction	Food	Reproduction
24	Food	Reproduction	Food	Reproduction
25	Food	Reproduction	Food	Reproduction
<hr/>				
* Food and reproduction				

Table 7. Limiting life requisites for moose which yielded the lowest habitat suitability indices in shrub. HSI's were calculated using both a geometric mean and a multiplicative mean on data collected both ocularly and by subsample.

<u>Participant</u>	<u>Ocular</u>		<u>Subsample</u>	
	Multiplicative	Geometric	Multiplicative	Geometric
<b>May</b>				
1	Interspersion	Reproduction	Food	Reproduction
2	Interspersion	Reproduction	Food	Reproduction
3	Interspersion	Reproduction	Food	Reproduction
4	Reproduction	Reproduction	Reproduction	Reproduction
5	Reproduction	Reproduction	Food	Reproduction
6	Reproduction	Reproduction	Food	Reproduction
7	Reproduction	Reproduction	Food	Reproduction
8	Interspersion	Reproduction	Food	Reproduction
<b>July</b>				
9	Interspersion	Reproduction	Interspersion	Reproduction
10	Interspersion	Reproduction	Interspersion	Reproduction
11	Food	Reproduction	Interspersion	Reproduction
12	Interspersion	Reproduction	Interspersion	Reproduction
13	Food	Reproduction	Reproduction	Reproduction
14	Interspersion	Reproduction	Reproduction	Reproduction
<b>September</b>				
15	Food	Reproduction	Food	Reproduction
16	Food	Reproduction	Food	Reproduction
17	Food	Reproduction	Food	Reproduction
18	Food	Reproduction	Food	Reproduction
19	Food	Reproduction	Food	Reproduction
20	Food	Reproduction	Food	Reproduction
21	Food	Reproduction	Food	Reproduction
22	Food	Reproduction	Food	Reproduction
23	Food	Reproduction	Food	Reproduction
24	Food	Reproduction	Food	Reproduction
25	Food	Reproduction	Food	Reproduction



May (ocular inventory) and July (both inventories), but in September food was determined to be limiting exclusively.

Willow ptarmigan    Reproduction was the exclusive limiting life requisite for willow ptarmigan. Willow ptarmigan breed at elevations of 610-915 m (2000-3000 ft) in interior Alaska (Weeden pers. comm.). Since the shrub sites at Bonanza Creek were well below this level at 100 m (330 ft) breeding would not occur and reproduction could be considered the limiting factor.

Precision of limiting habitat suitability indices (LHSI's)

For HEP to be accepted as a valid approach of assessing habitat quality, results from the system must be repeatable (precise) (Holmberg 1977). Different biologists, or teams of biologists, should be able to independently measure critical habitat characteristics, plug them into evaluation models and come up with comparable habitat ratings. It has already been demonstrated that the mean value and variability of many habitat characteristics were significantly influenced by the method used for estimation. Mean ocular estimates were generally greater and more variable than were subsample estimates of a habitat attribute. Similar sources of variability might also be operating on LHSI's. Both the habitat characteristic inventory method and the mathematical function used to calculate LHSI's are possible sources of variation in LHSI values.

A one-way analysis of variance (anova) was performed to determine if the mean LHSI values of treatment groups were equal;

groups were based on the method of habitat characteristic inventory and the mathematical function used to calculate LHSI values.

The one-way anova tests the equality of two or more data sets by simultaneously considering differences in variances and means (Davis 1973). Equality or inequality of variances was indicated by the Levene's test statistic, which has been shown to be robust against departures from normality (Levene 1960). One of two statistics were generated to indicate equality of means. The F statistic was used if variances were found to be equal. The Brown-Forsythe statistic was used as a more robust indicator of equality of means if the variances were shown to be unequal (Brown and Forsythe 1974). The variability of LHSI's is an indication of a treatment group's precision. Low variability and precision are synonymous. For instance, if a significant difference exists in the variability of LHSI values generated from ocular and subsample data, one population of LHSI's must be less variable, or more precise, than the other. The reliability that comes with greater precision is a desirable aspect of any evaluation system and should be incorporated into HEP.

Subjective ratings were also examined to determine the extent to which they agreed with LHSI's. A one-way anova was performed to determine if mean LHSI's were significantly different from subjective ratings. Levene's test was used to indicate equality or inequality of variances. Results from these tests give an indication of the increase in precision derived from modelling species' habitat requirements compared to the subjective approach of habitat quality assessment.

A comparison of ocular means and subsample means

The precision and mean value of habitat suitability indices assigned by some evaluation models to a test site were effected by the method (ocular or subsample) in which habitat characteristics data were collected.

Using the multiplicative mean the snowshoe hare, moose and moose-winter models showed significant differences in variability of LHSI's derived from data gathered by different inventory techniques (Table 8). In each case the LHSI'S generated with ocular data were significantly less precise than those using subsample data. Mean ocular LHSI's were also statistically greater than mean subsample values for these three models when calculated by either mathematical function. The spruce grouse and red squirrel models were less sensitive to differences in habitat characteristics due to inventory method. Although mean value and variability of LHSI's for these species was greater using ocular data than subsample data, the difference of these statistics was not significant.

Variability of ocular and subsample LHSI's determined by the geometric mean were not statistically different for any mixed forest evaluation species (Table 8).

In shrub the willow ptarmigan model showed significantly greater variability in LHSI's based on subsample data than on ocular data (Table 9); this was the only model in either habitat type in which this occurred. The mean ocular and subsample LHSI values produced by this model were not statistically different. The moose model produced

Table 8. Results from a one-way analysis of variance testing differences between mixed forest limiting HSI's calculated with ocular and subsample estimates of habitat characteristics. Results using both a multiplicative mean and a geometric mean are presented. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)				
	Ocular	Subsample	Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
<hr/>					
Multiplicative					
Grouse	.521(.110)	.517(.161)	1.35	0.01	
Grouse-winter	.878(.262)	.758(.250)	0.00	3.06	
Hare	.235(.146)	.086(.063)	16.24 *		24.39(df=1,37) *
Squirrel	.101(.083)	.079(.091)	0.54	0.91	
Moose	.029(.015)	.018(.011)	4.38 *		7.99(df=1,50) *
Moose-winter	.033(.013)	.024(.010)	7.22 *		6.23(df=1,50) *
<hr/>					
Geometric					
Grouse	.652(.057)	.605(.121)	0.04	3.47	
Grouse-winter	.949(.124)	.844(.216)	2.40	4.97 *	
Hare	.598(.133)	.426(.087)	3.64	32.42 *	
Squirrel	.613(.072)	.579(.068)	1.24	3.26	
Moose	.476(.050)	.438(.039)	0.00	9.86 *	
Moose-winter	.558(.043)	.533(.035)	2.21	5.50 *	

Table 9. Results from a one-way analysis of variance testing differences between shrub limiting HSI's calculated with ocular and subsample estimates of habitat characteristics. Results using both a multiplicative mean and a geometric mean are presented. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)		Levene's ( $\alpha^2=1,52$ )	F-Value ( $df=1,52$ )	Brown-Forsythe
	Ocular	Subsample			
Multiplicative					
Ptarmigan	.792(.326)	.658(.419)	6.05		1.69( $df=1,49$ )
Moose	.245(.092)	.192(.091)	0.02	4.46 *	
Geometric					
Ptarmigan	.834(.308)	.731(.394)	4.40 *		1.14( $df=1,49$ )
Moose	.563(.052)	.511(.038)	3.78	17.81 *	

mean LHSI values which were significantly higher when using data collected ocularly rather than by subsample; for geometric means, the ocular method LHSI values were more variable, but no difference in precision existed for multiplicative means LHSI's.

These results suggest the following.

- 1.) For those models which showed a significant difference in the variability of LHSI's, subsample data generally produced statistically more precise (less variable) LHSI values than ocular data. The one exception was the willow ptarmigan model.
- 2.) For those models which showed a significant difference in mean LHSI values, ocular data invariably produced significantly higher ratings than those generated with subsample data.
- 3.) The variability of ocular LHSI's and subsample LHSI's calculated by the geometric mean were not significantly different for any mixed forest evaluation model.

#### A comparison of multiplicative means and geometric means

The most pronounced feature of the results from this anova is the difference in mean LHSI values. The geometric mean produced larger mean values for every species model, using either ocular or subsample data (Table 10). For every model except the spruce grouse-winter and willow ptarmigan models, significant difference resulted. The high LHSI values generated by the geometric mean can be explained by the compensatory nature of the function; the low value of one variable is offset by high values for other variables (USFWS

Table 10. Results from a one-way analysis of variance testing differences between mixed forest limiting HSI's calculated using both a multiplicative mean and a geometric mean. Results are presented for LHSI's determined from both ocular and subsample data. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)				
	Multiplicative	Geometric	Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
Ocular					
Grouse	.521(.110)	.652(.057)	9.28 *		31.36(df=1,41) *
Grouse-winter	.878(.262)	.949(.124)	6.91 *		1.69(df=1,38)
Hare	.235(.146)	.598(.133)	0.41	94.57 *	
Squirrel	.101(.083)	.613(.072)	0.16	596.45 *	
Moose	.029(.015)	.476(.050)	10.91 *		1997.84(df=1,32) *
Moose-winter	.033(.013)	.558(.043)	24.44		3997.40(df=1,33) *
Subsample					
Grouse	.517(.161)	.605(.121)	5.44 *		5.26(df=1,50) *
Grouse-winter	.758(.250)	.844(.216)	1.27	1.89	
Hare	.086(.063)	.426(.087)	2.61	277.32 *	
Squirrel	.079(.091)	.579(.068)	0.21	534.89 *	
Moose	.018(.011)	.438(.039)	65.57 *		2995.58(df=1,31) *
Moose-winter	.024(.010)	.533(.035)	15.91 *		5326.02(df=1,32) *

1980b). Outrider values have a negligible influence on the final product. With the multiplicative mean function this relationship does not exist. Low values are not balanced by higher values and so have a much more significant influence on the final product. For example, if variables 1 and 2 had suitability indices of 0.90 and 0.30, respectively, the geometric mean would produce an HSI of 0.51, whereas the multiplicative mean would be 0.27.

The mathematical functions used to calculate LHSI's also effected the precision and mean values of those LHSI's. The spruce grouse, moose and moose-winter mixed forest evaluation models showed consistent significant differences in LHSI variability for the ocular or subsample data (Table 10). LHSI's generated by the multiplicative mean were more variable for the spruce grouse model; LHSI's generated by the geometric mean were more variable for the moose and moose-winter models. The snowshoe hare and red squirrel models produced LHSI's which showed no significant differences in variability for the two functions.

In shrub, variability of LHSI's was consistently significantly greater for LHSI's generated by the geometric mean (Table 11). The willow ptarmigan model produced LHSI's which were equally variable for either function.

These results suggest the following.

- 1.) The geometric mean consistently rendered higher mean LHSI values than did the multiplicative mean.
- 2.) Neither the geometric mean or multiplicative mean was found



Table 11. Results from a one-way analysis of variance testing differences between shrub limiting HSI's calculated using both a multiplicative mean and a geometric mean. Results are presented for LHSI's determined from both ocular and subsample data. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)		Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
	Multiplicative	Geometric			
Ocular					
Ptarmigan	.792(.326)	.834(.308)	0.72	0.24	
Moose	.245(.245)	.563(.052)	9.36 *		241.21(df=1,41) *
Subsample					
Ptarmigan	.658(.419)	.731(.394)	0.86	0.43	
Moose	.192(.019)	.511(.038)	26.83 *		279.74(df=1,35) *

to render exclusively more variable LHSI values.

### Subjective ratings

All species models from both habitat types showed a significant difference in the variability of LHSI's and the variability of subjective ratings (Tables 12-15). This occurred for both mathematical functions using either ocular or subsample data, with subjective ratings significantly more variable than LHSI values for all but a few cases. The exceptions were: 1) the willow ptarmigan-winter model produced LHSI's which were significantly more variable than subjective ratings, and 2) the spruce grouse-winter model using the multiplicative mean showed no difference in variability. Other studies (Mule' 1982; Baskett et al 1980; Ellis et al 1978, 1979; Flood 1977; Sparrowe and Sparrowe 1978) have reported similarly impressive increases in precision of habitat scores when using a handbook approach as opposed to personal opinion.

Mean LHSI values were significantly different from mean subjective ratings for all but the multiplicative mean snowshoe hare and red squirrel models. Results were mixed concerning relative magnitude of LHSI's and subjective ratings.

These results suggest the following.

- 1.) Subjective ratings tended to be significantly more variable than the LHSI's from all models tested regardless of how the LHSI's were determined.
- 2.) Subjective ratings overwhelmingly differed from mean LHSI

Table 12. Results from a one-way analysis of variance testing differences between mixed forest limiting HSI's calculated with ocular data and subjective ratings. Results using both a multiplicative mean and a geometric mean are presented. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)				
	Ocular	Subjective	Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
<hr/>					
Multiplicative					
Grouse	.521(.110)	.296(.282)	30.06 *	17.19 *	11.27(df=1,33) *
Grouse-winter	.878(.262)	.522(.315)	1.74		
Hare	.235(.146)	.271(.249)	24.06 *		0.25(df=1,36)
Squirrel	.101(.083)	.239(.278)	42.80 *		3.93(df=1,30)
Moose	.029(.015)	.528(.142)	73.10 *		84.17(df=1,27) *
Moose-winter	.033(.013)	.755(.188)	80.17 *		264.30(df=1,17) *
<hr/>					
Geometric					
Grouse	.652(.057)	.296(.282)	49.77 *		30.42(df=1,29) *
Grouse-winter	.949(.124)	.522(.315)	19.64 *		30.09(df=1,20) *
Hare	.598(.133)	.271(.249)	28.26 *		21.12(df=1,35) *
Squirrel	.613(.072)	.239(.278)	46.12 *		29.50(df=1,29) *
Moose	.476(.050)	.528(.142)	56.06 *		0.88(df=1,29) *
Moose-winter	.588(.043)	.755(.188)	51.81 *		19.10(df=1,18) *

Table 13. Results from a one-way analysis of variance testing differences between mixed forest limiting HSI's calculated with ocular data and subjective ratings. Results using both a multiplicative mean and a geometric mean are presented. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)				
	Subsample	Subjective	Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
<hr/>					
Multiplicative					
Grouse	.517(.161)	.296(.282)	17.98 *	7.92 *	9.84(df=1,39) *
Grouse-winter	.758(.250)	.522(.315)	1.85		
Hare	.086(.063)	.271(.249)	55.29 *		7.47(df=1,29) *
Squirrel	.079(.091)	.239(.278)	44.65 *		5.26(df=1,31) *
Moose	.018(.011)	.528(.142)	76.16 *		87.75(df=1,17) *
Moose-winter	.024(.010)	.755(.188)	85.51 *		270.21(df=1,17) *
<hr/>					
Geometric					
Grouse	.605(.121)	.296(.282)	35.87 *		20.80(df=1,34) *
Grouse-winter	.844(.216)	.522(.315)	5.40 *		14.41(df=1,27) *
Hare	.426(.087)	.271(.249)	44.20 *		5.13(df=1,30) *
Squirrel	.579(.068)	.239(.278)	51.39 *		24.46(df=1,29) *
Moose	.438(.039)	.528(.142)	58.92 *		2.68(df=1,28) *
Moose-winter	.533(.035)	.755(.188)	59.92 *		24.44(df=1,18) *

Table 14. Results from a one-way analysis of variance testing differences between shrub limiting HSI's calculated with ocular data and subjective ratings. Results using both a multiplicative mean and a geometric mean are presented. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)		Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
	Ocular	Subjective			
Multiplicative					
Ptarmigan	.792(.326)	.162(.235)	10.54 *		2308.12(df=1,29) *
Moose	.245(.245)	.327(.332)	8.27 *		12.14(df=1,39) *
Geometric					
Ptarmigan	.834(.308)	.162(.235)	37.50 *		3675.83(df=1,27) *
Moose	.563(.052)	.327(.332)	20.01 *		938.91(df=1,40) *

Table 15. Results from a one-way analysis of variance testing differences between shrub limiting HSI's calculated with ocular data and subjective ratings. Results using both a multiplicative mean and a geometric mean are presented. Equality of variances is indicated by the Levene's statistic. Equality of means is indicated by the F-statistic when variances are equal and by the Brown-Forsythe statistic in cases of unequal variances. An asterisk indicates a significant difference at  $p=.05$ .

	Mean(S.D.)		Levene's (df=1,52)	F-Value (df=1,52)	Brown-Forsythe
	Subsample	Subjective			
Multiplicative					
Ptarmigan	.658(.419)	.162(.235)	69.13 *		2741.41(df=1,34) *
Moose	.192(.019)	.327(.332)	7.98 *		201.80(df=1,33) *
Geometric					
Ptarmigan	.732(.394)	.162(.235)	70.60 *		3306.78(df=1,27) *
Moose	.511(.038)	.327(.332)	15.52 *		177.41(df=1,34) *

values regardless of how the LHSI's were determined.

#### Accuracy of limiting habitat suitability indices (LHSI's)

Two procedures were utilized to determine how well habitat values generated by the HEP models and subjective ratings agreed with expert ratings. A t-test was used to test the hypothesis that the expert rating and the LHSI's for an evaluation element (or subjective rating for the same evaluation species) came from the same population. The expert rating was considered a sample of one and so did not effect degrees of freedom or contribute to within group variance (Sokal and Rohlf 1969). The second procedure looks at the absolute difference between LHSI's and expert ratings. Plus or minus 0.1 HSI from the expert rating was considered to be the acceptable range of accuracy.

#### Expert ratings

Values assigned by experts to the evaluation elements are presented in Table 16. Where two or more experts rated the same species their ratings were within 0.1 of each other. Although habitat was rated by more than one expert for only two species (moose and red squirrel), the close agreement of their ratings support the supposition that an expert can accurately rate a habitat.

#### Test of equality

#### LHSI's generated from ocular data

Table 16. Expert ratings of evaluation elements in mixed forest and shrub habitat.

	<u>Mixed forest</u>		<u>Shrub</u>	
	Summer	Winter	Summer	Winter
Spruce grouse				
Weeden	0.4	0.5	0.2	0.0
Willow ptarmigan				
Weeden	0.0	0.0	0.0	0.6
Snowshoe hare				
Wolff	0.2	0.1	0.3	0.6
Red squirrel				
Wolff	0.7	0.7	0.0	0.0
Nodler	0.8	0.8	0.0	0.0
Moose				
Wolff	0.0	0.0	0.8	0.9
Gasaway	0.1	0.0	0.9	0.9
Dubois	0.0	0.0	0.9	0.8



Overall and seasonally, LHSI's produced by both the multiplicative and geometric models were significantly different from the expert ratings for all evaluation elements except the spruce grouse multiplicative model and the red squirrel geometric model (Table 17).

LHSI's were in better agreement with expert ratings in shrub than in mixed forest (Table 18). Moose (multiplicative mean) and willow ptarmigan-winter (geometric mean) differed from the expert rating when values from all tests were combined. The willow ptarmigan results showed complete agreement with the expert ratings for both the multiplicative and geometric means.

The agreement in ptarmigan results between the expert rating and LHSI's can be attributed to one habitat characteristic -- elevation above sea level. This characteristic was not estimated individually by the participants. I derived the value (100 m) for this characteristic from a topographic map and assigned that same value to each participant's set of habitat characteristic estimates. A measurement of 100 m translated to a suitability index of 0.00 for the elevation variable. By virtue of this 0.00 suitability index the reproductive habitat component also dropped to zero and became the limiting factor for willow ptarmigan for all participants.

#### LHSI's generated from subsampled data

There was little agreement between expert ratings and LHSI's produced from subsample data, by using either the multiplicative or

Table 17. Values from a t-test comparing LHSI's with expert ratings for mixed forest evaluation models. Indices were calculated using the multiplicative mean and geometric mean with ocular data. Asterisks indicate a significant difference at  $p=.05$ .

	May	July	September	Overall
<b>Multiplicative</b>				
Spruce grouse	3.33 *	2.14	2.19	1.92
Spruce grouse (winter)	5.69 *	9.24 *	3.55 *	2.93 *
Snowshoe hare	0.21	6.72 *	4.14 *	8.05 *
Red squirrel	3.57 *	3.34 *	2.96 *	2.70 *
Moose	23.85 *	5.72 *	11.74 *	6.16 *
Moose (winter)	76.92 *	18.72 *	25.51 *	15.04 *
<b>Geometric</b>				
Spruce grouse	2.62 *	8.42 *	10.68 *	3.83 *
Spruce grouse (winter)	6.44 *	17.13 *	7.35 *	4.28 *
Snowshoe hare	8.61 *	12.48 *	14.69 *	7.84 *
Red squirrel	0.31	0.89	0.52	0.80
Moose	119.56 *	323.32 *	36.40 *	26.56 *
Moose (winter)	127.56 *	293.66 *	54.35 *	37.82 *

Table 18. Values from a t-test comparing LHSI's with expert ratings for shrub evaluation models. Indices were calculated using the multiplicative mean and geometric mean with ocular data. Asterisks indicate a significant difference at  $p=.05$ .

	May	July	September	Overall
<b>Multiplicative</b>				
Willow ptarmigan	0.00	0.00	0.00	0.00
Willow ptarmigan (winter)	31.40 *	2.06	1.34	2.14
Moose	1.64	4.51 *	1.46	4.75 *
<b>Geometric</b>				
Willow ptarmigan	0.00	0.00	0.00	0.00
Willow ptarmigan (winter)	22.96 *	2.31	3.22 *	3.03 *
Moose	0.37	0.42	0.54	0.52

geometric function (Table 19). Overall, multiplicative LHSI's for the spruce grouse, red squirrel, moose and moose-winter were significantly different than the expert ratings. In the May test, LHSI's for all the species differed from the expert rating.

The geometric mean produced LHSI's for snowshoe hare, moose and moose-winter which overall were significantly different from expert evaluation.

The September test had the least number of significant differences for both treatments.

In shrub the pattern of significant differences was the same for both mathematical treatments (Table 20). Overall and seasonally, the moose LHSI's were different from values assigned by the experts. As with ocular data, the subsampled data generated LHSI's for willow ptarmigan which were in complete agreement with expert ratings.

#### Subjective ratings

No winter comparisons from the May test could be made since May test participants were not required to give a subjective winter rating.

Overall in mixed forest, expert and subjective ratings differed for spruce grouse-winter, moose and moose-winter (Table 21). None of the May comparisons were significantly different. The ratings for snowshoe hare were not significantly different for any of the periods.

Overall in the shrub, subjective and expert ratings for the willow ptarmigan differed only for the winter ratings.

Table 19. Values from a t-test comparing LHSI's with expert ratings for mixed forest evaluation models. Indices were calculated using the multiplicative mean and geometric mean with subsample data. Asterisks indicate a significant difference at  $p=.05$ .

	May	July	September	Overall
<b>Multiplicative</b>				
Spruce grouse	-2.64 *	2.14	-0.90	-3.69 *
Spruce grouse (winter)	-2.55 *	-21.82 *	-0.89	-3.47 *
Snowshoe hare	3.33 *	0.45	1.79	0.30
Red squirrel	11.54 *	2.81 *	24.18 *	3.90 *
Moose	27.22 *	3.98 *	11.47 *	2.76 *
Moose (winter)	25.79 *	4.35 *	9.88 *	2.70 *
<b>Geometric</b>				
Spruce grouse	-12.34 *	-13.73 *	-0.87	-1.09
Spruce grouse (winter)	-5.29 *	-45.95 *	-0.68	-1.97
Snowshoe hare	-2.62 *	-2.93 *	-2.39 *	-2.67 *
Red squirrel	2.10	0.61	321.46 *	0.98
Moose	12.02 *	-21.11 *	-8.19 *	-5.04 *
Moose (winter)	13.99 *	8.08 *	10.17 *	7.45 *

Table 20. Values from a t-test comparing LHSI's with expert ratings for shrub evaluation models. Indices were calculated using the multiplicative mean and geometric mean with ocular data. Asterisks indicate a significant difference at  $p=.05$ .

	May	July	September	Overall
<b>Multiplicative</b>				
Willow ptarmigan	0.00	0.00	0.90	0.00
Willow ptarmigan (Winter)	-0.22	-7.33 *	0.30	-0.13
Moose	10.56 *	22.73 *	13.60 *	6.93 *
<b>Geometric</b>				
Willow ptarmigan	0.00	0.00	0.00	0.00
Willow ptarmigan (winter)	-0.37	-2.96 *	0.07	-0.31
Moose	13.99 *	8.08 *	10.17 *	7.45 *

Table 21. Values from a t-test comparing subjective ratings with expert ratings for both mixed forest and shrub habitats. Asterisks indicate a significant difference at  $p=.05$ .

	May	July	September	Overall
<b>Mixed forest</b>				
Spruce grouse	-1.88	12.63 *	3.96 *	0.99
Spruce grouse (winter)		4.46 *	7.55 *	5.94 *
Red squirrel	-0.08	12.13 *	10.40 *	2.25
Snowshoe hare	-2.35	-1.36	-2.36	-2.05
Moose	-2.25	-3.36 *	3.55 *	-2.87 *
Moose (winter)		-5.27 *	3.69 *	4.16 *
<b>Shrub</b>				
Willow ptarmigan	-1.79	-0.74	-1.91	-1.20
Willow ptarmigan (winter)		7.44 *	9.01 *	8.78 *
Moose	-1.99	5.21 *	6.89 *	1.79

Absolute difference between LHSI's and expert ratings

Moose The moose and moose-winter models produced the most accurate ratings of any mixed forest models (Figures 4 and 5 respectively). Using either ocular or subsample data with the multiplicative mean, mean differences from the expert ratings were all less than 0.1 HSI, standard deviations of the mean differences were very small and seasonal variation was minimal. The geometric mean function produced mean differences which were three or four times greater than those generated by the multiplicative mean. Standard deviation of ratings and seasonal variation were comparable to those produced by the multiplicative mean.

The moose model for shrub habitat did not produce ratings within acceptable limits of accuracy (Figure 6). The geometric mean produced ratings which were closer to acceptable levels of accuracy than did the multiplicative mean, but the ratings from the geometric mean were as variable or more variable than those from the multiplicative mean. There was little seasonal variation in the results from any of the treatments.

I believe that the accuracy of the ratings produced by the moose and moose-winter models is related to the low quality of the habitat for moose and large number of variables used in calculating LHSI's. Two of the experts assigned a rating of 0.1 HSI to the mixed forest habitat while the third rated it as having no value to moose. Ratings were the same for winter range. The HSI's produced by the moose model using the multiplicative mean agreed with the experts' assessment. On



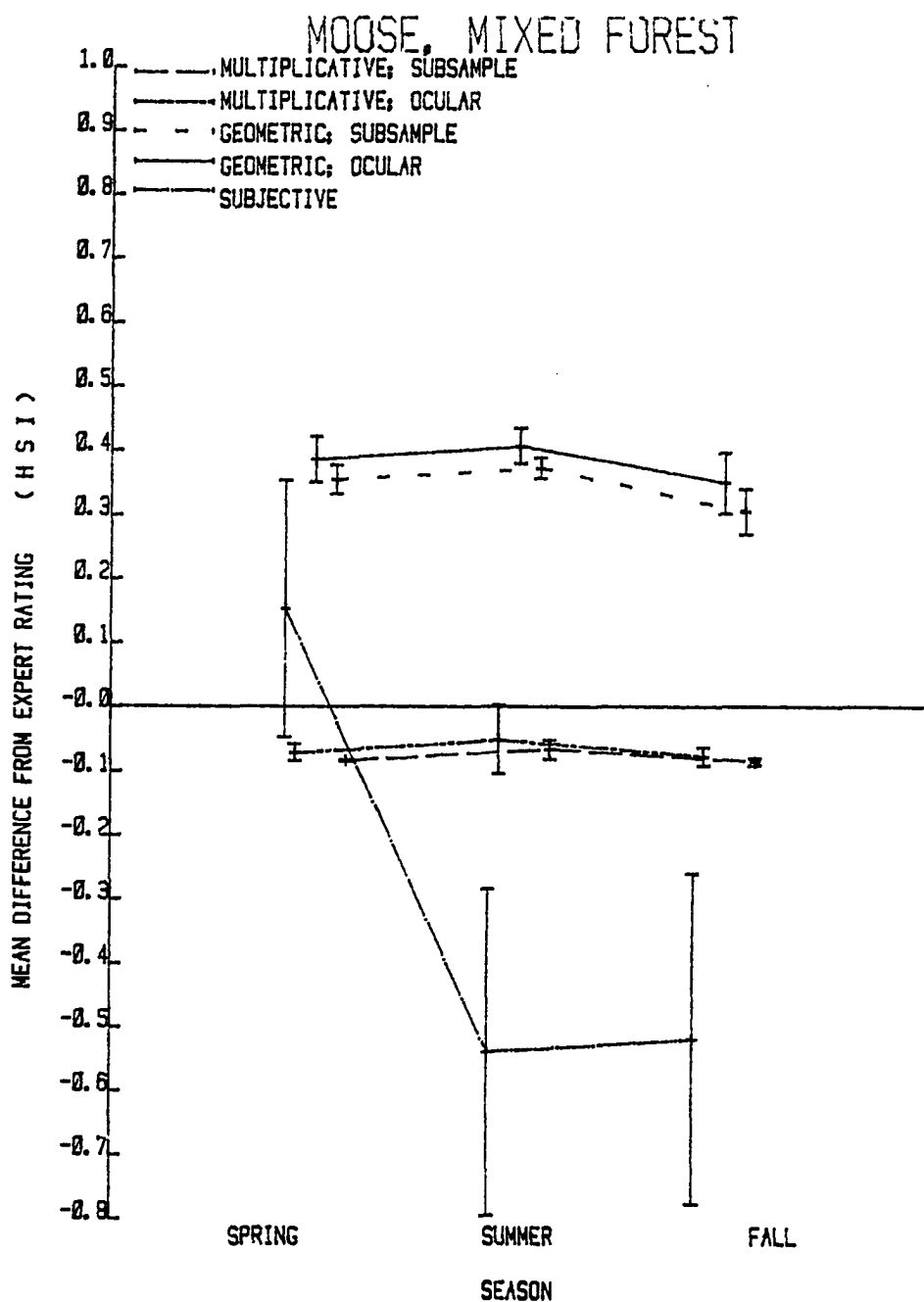


Figure 4. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the moose model in mixed forest. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

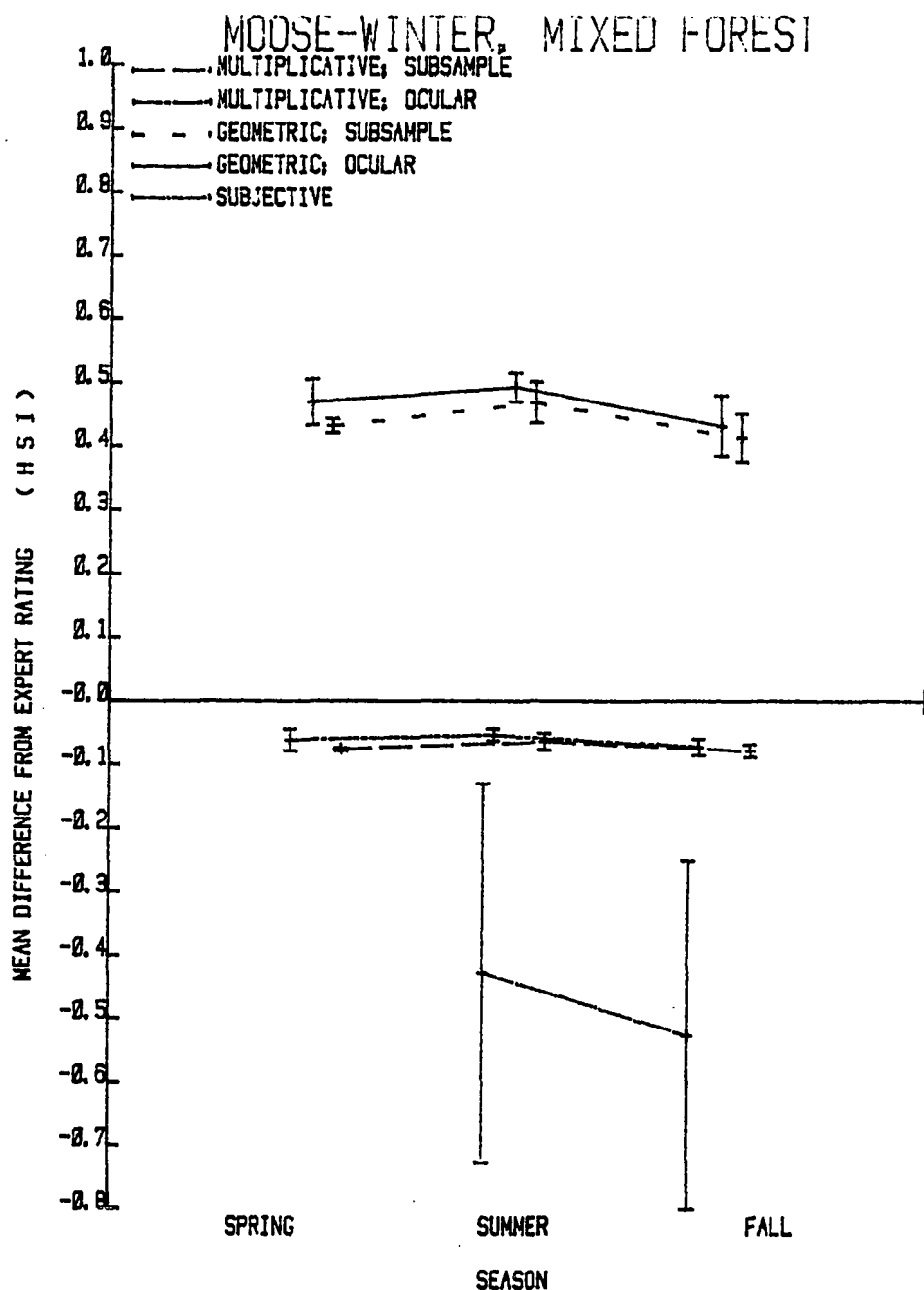


Figure 5. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the moose-winter model in mixed forest. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

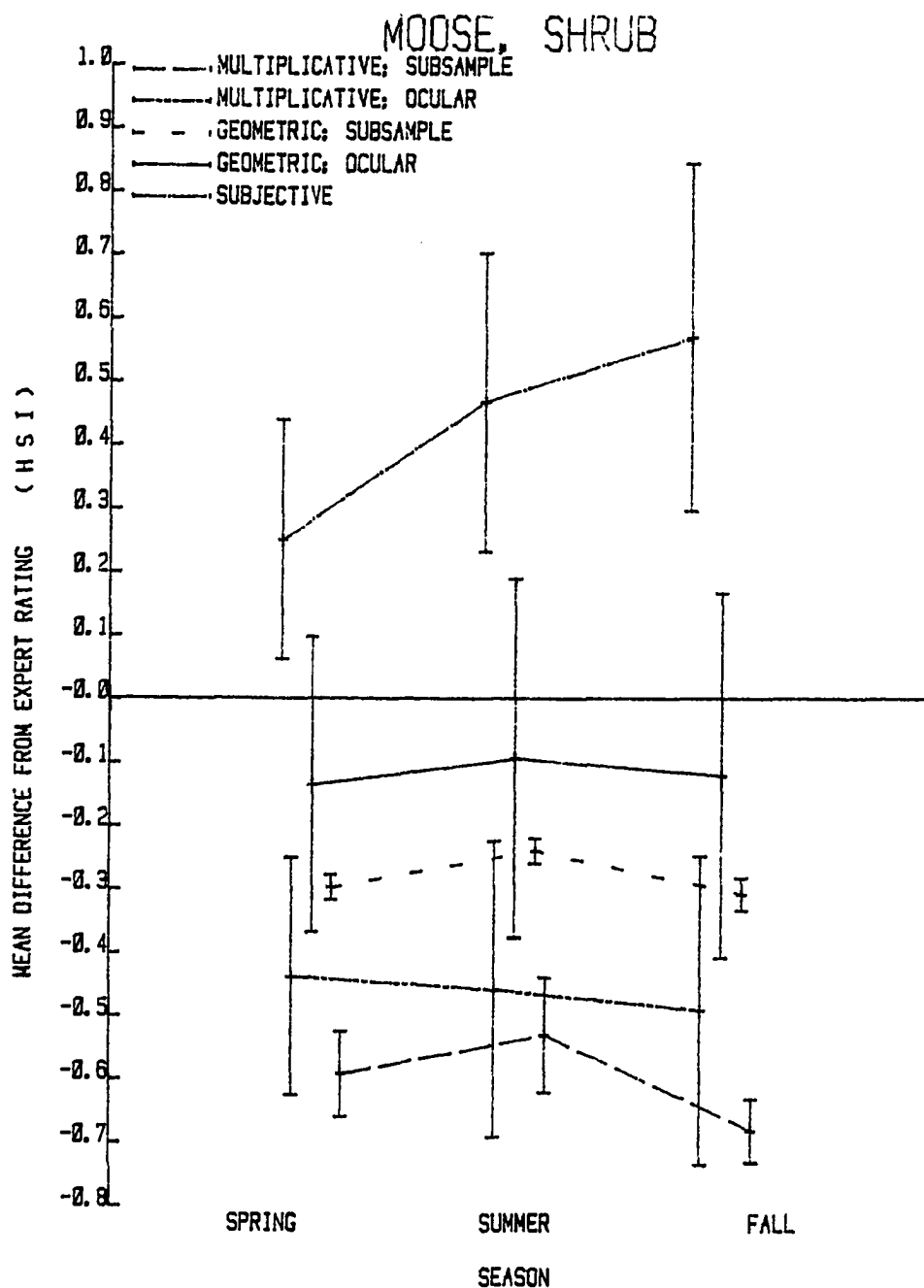


Figure 6. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the moose model in shrub. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

the other hand, in the shrub habitat, which was judged to be excellent by the experts (ratings of 0.9, 0.9, and 0.8), LHSI's showed little accuracy or precision (Figure 6).

The moose is an ecologically complex species utilizing a wide range of habitat types and undergoing seasonal migrations. The moose model contains a large number of variables indicating the intricate relationship of factors involved in providing good moose habitat. It is somewhat surprising, therefore, that the moose model performed so well, while simpler models, such as that for the red squirrel, produced highly variable ratings which did not agree well with the opinion of the species experts.

The more variables that are involved in the calculation of LHSI's the greater is the likelihood that the resultant LHSI's will be small, especially when using the multiplicative mean. This is due to the effect of multiplying factors (suitability indices) with values less than 1.0. Indices will be less than 1.0 for all parameters that are not in what is considered to be the optimum range for a species as indicated by the transformation curves.

As an example, consider a model which involves five habitat characteristics for a life requisite ( $X_n$ ). If each characteristic is in the optimum range of values the suitability index will be

$$X_n = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0$$

$$= 1.0 \text{ (multiplicative mean)}$$

$$X_n = ( 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 )^{1/5}$$

= 1.0 (geometric mean).

If the value of the characteristics are high but not optimum, say 0.9, the resulting LHSI will be substantially reduced for the multiplicative mean

$$\begin{aligned} X_n &= 0.9 \times 0.9 \times 0.9 \times 0.9 \times 0.9 \\ &= 0.59. \end{aligned}$$

With the geometric mean the effect is not noticeable

$$\begin{aligned} X_n &= ( 0.9 \times 0.9 \times 0.9 \times 0.9 \times 0.9 )^{1/5} \\ &= 0.9. \end{aligned}$$

The effect of a large number of variables with SI values less than 1.0 becomes more pronounced as more variables are added. With only two variables the HSI value is

$$\begin{aligned} X_n &= 0.9 \times 0.9 \\ &= 0.81. \end{aligned}$$

With three factors the value is 0.73; with four factors, 0.66; and with five factors, 0.59. The consequences of several variables is exacerbated when one or several of the SI values is low

$$\begin{aligned} X_n &= 0.9 \times 0.9 \times 0.9 \times 0.9 \times 0.4 \\ &= 0.26. \end{aligned}$$

Since models with a large number of variables are likely to produce low LHSI's, those ratings will probably agree with species experts only when the habitat is of poor quality. This appears to be what happened with the moose model in mixed forest using the multiplicative mean.

Red squirrel The red squirrel model was the only mixed forest model to perform better with the geometric mean than with the multiplicative mean. The most accurate ratings for this model resulted from using the geometric mean in conjunction with subsample data (Figure 7). Although mean differences for the Spring and Fall tests were slightly greater than 0.1 HSI, the variation of these ratings was small. The accuracy of the results is questionable. The geometric mean used with ocular data produced fairly accurate ratings but their variation was very large and therefore the ratings were unacceptable. For example, the mean difference from expert ratings for the summer test was slightly greater than 0.1 HSI. But, with the large variability of the ratings the standard deviation extends from .4 to -.2 HSI. The values at the extremes of this spread certainly cannot be considered accurate.

Multiplicative mean generated ratings did not agree well with expert ratings. Mean differences were 3 or 4 times as great as those resulting from the geometric mean. Ocular data rendered noticeably more variable ratings than did subsample data. Ratings from the summer test were markedly the most variable of all tests.

Spruce grouse The spruce grouse model (multiplicative mean)

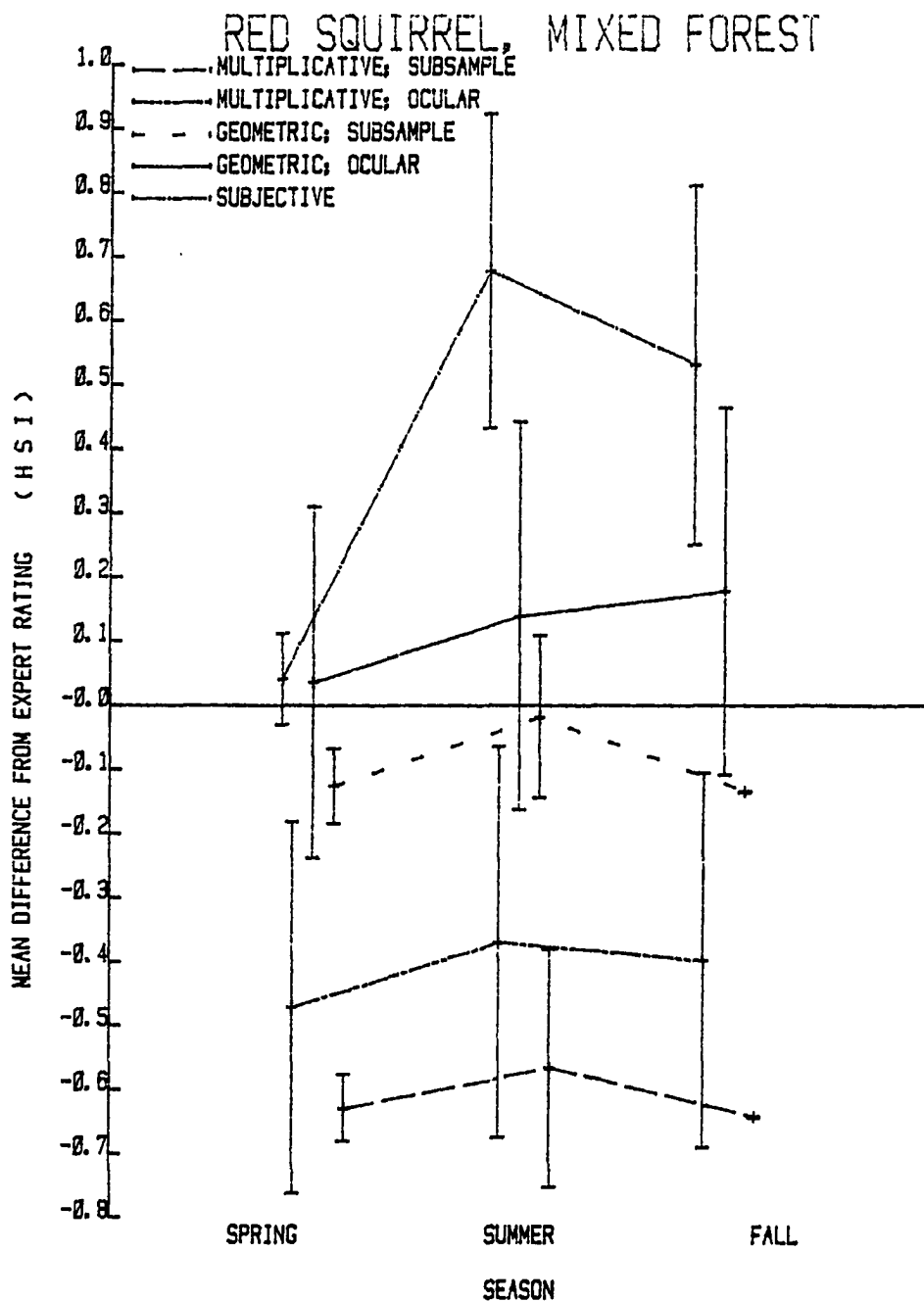


Figure 7. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the red squirrel model in mixed forest. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

produced LHSI's which were on the borderline of acceptable accuracy (Figure 8). The geometric mean produced slightly greater mean differences and so must be considered not as accurate (Figure 8). The multiplicative mean and geometric mean produced very similar ratings for the spruce grouse-winter model (Figure 9). In all cases the accuracy was poor compared to the rating of the spruce grouse authority.

Ocular and subsample data produced different patterns of seasonal variation. There was little seasonal variation in mean differences from the expert rating for both models using ocular data and variability did not markedly change. However, using subsample data, variability of Fall ratings greatly increased for both models. The added variability can probably be attributed to test participants' uncertainty in estimating senescent and live vegetation coverage in October. Subsampling appears to magnify this variability due to differences in perception of viable vegetation by the participants.

Snowshoe hare The snowshoe hare model produced consistently accurate ratings only when using subsample data with the multiplicative mean (Figure 10). The Spring and Fall tests produced accurate ratings but the Summer test results were unacceptable. Both the mean difference and variability of the mean greatly increased in the summer.

The geometric mean inflated mean differences for all tests compared to the ratings from the multiplicative mean, resulting in an unacceptable level of accuracy.



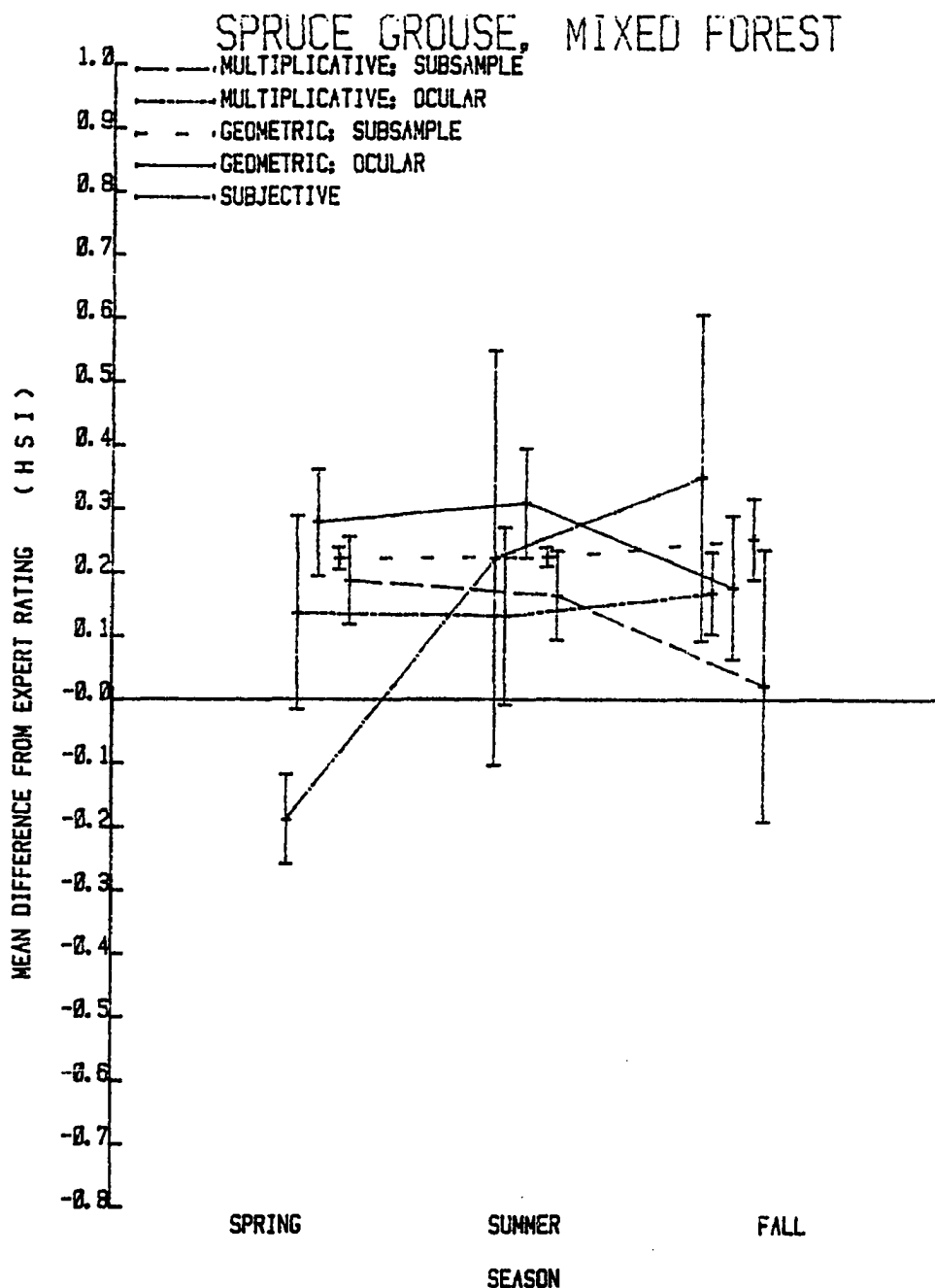


Figure 8. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the spruce grouse model in mixed forest. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

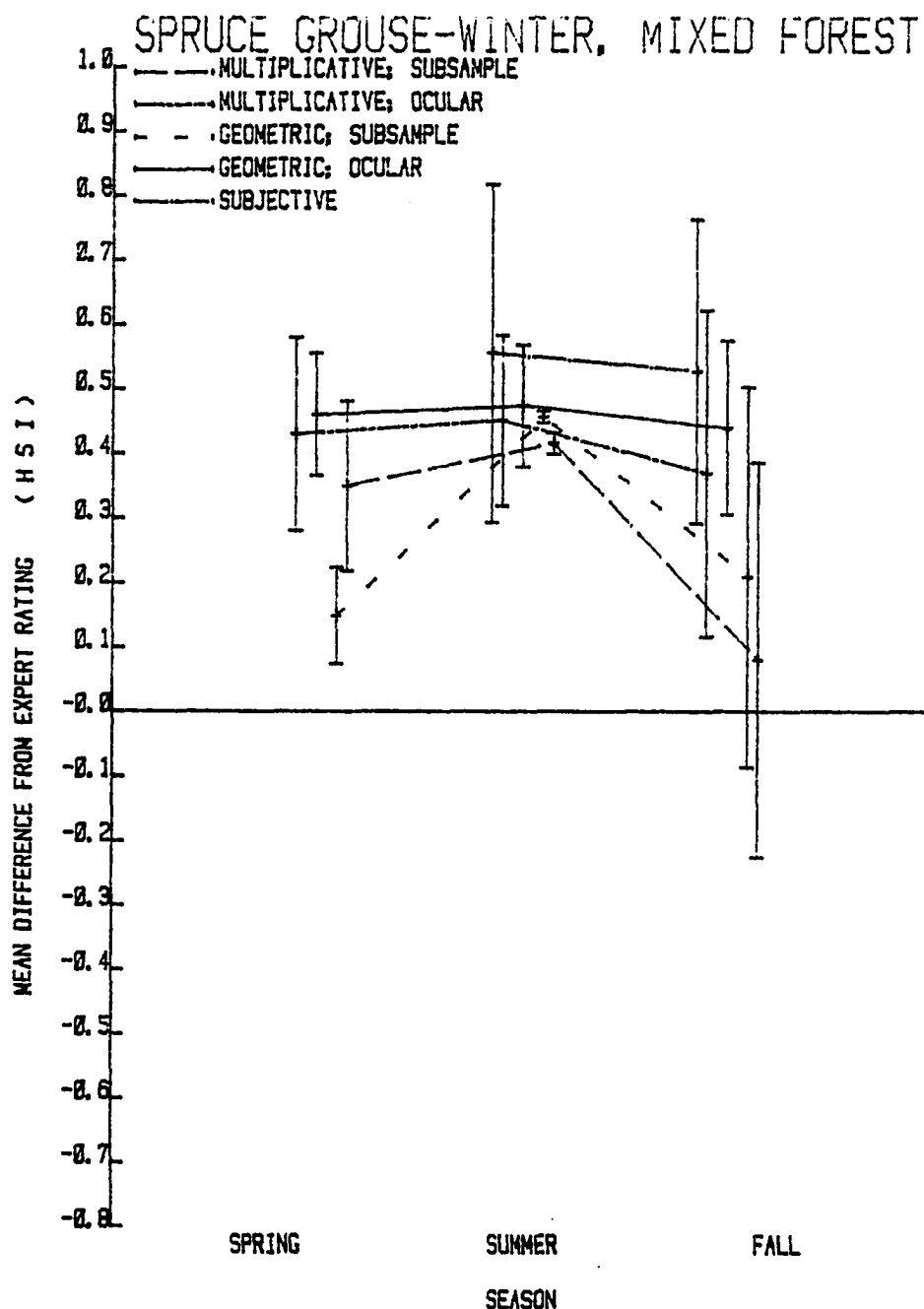


Figure 9. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the spruce grouse-winter model in mixed forest. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

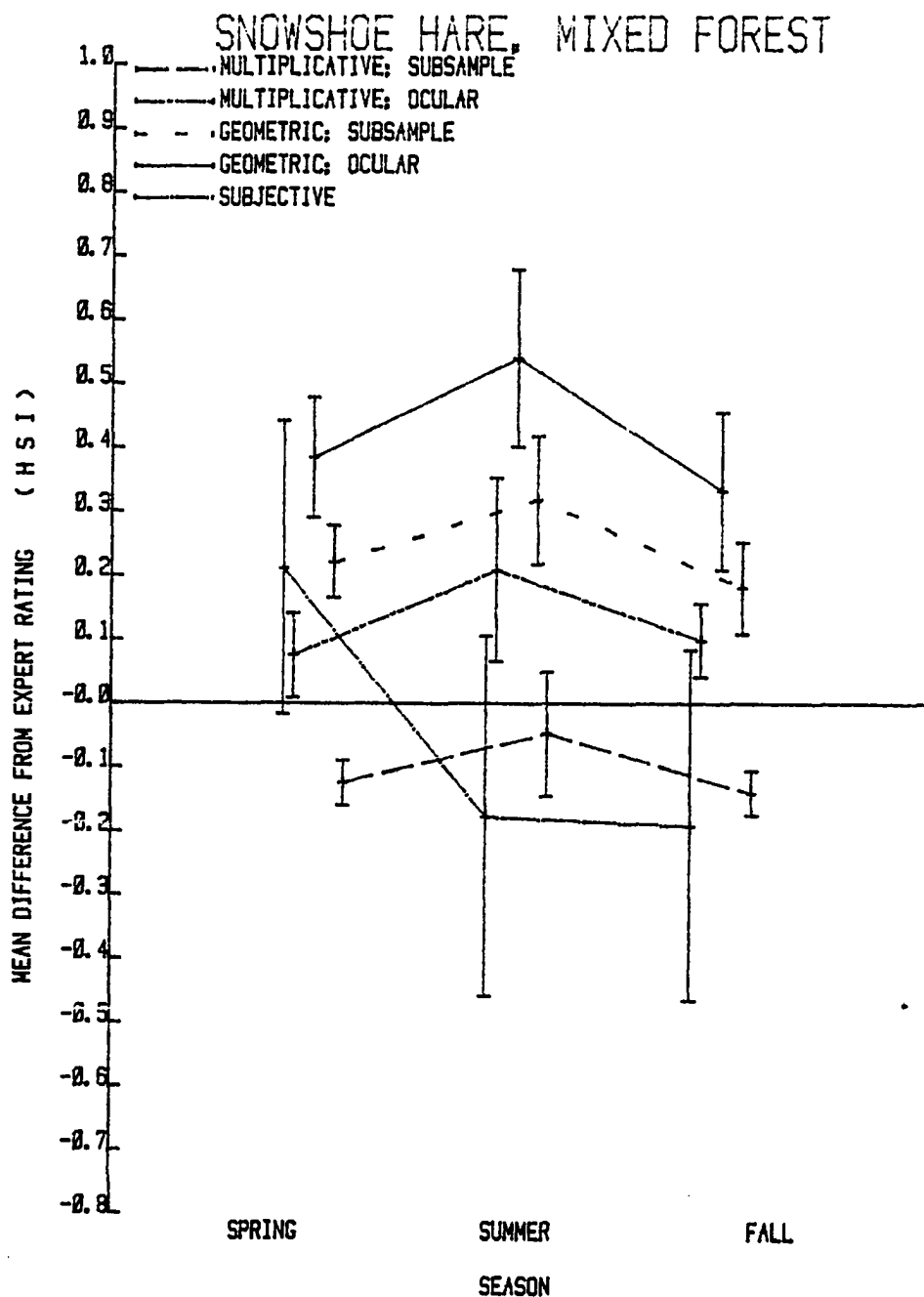


Figure 10. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the snowshoe hare model in mixed forest. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

Willow ptarmigan The willow ptarmigan model rendered ratings which were in complete agreement with the expert rating.

The willow ptarmigan-winter model did not produce consistently accurate ratings (Figure 11). Using ocular data, the pattern of seasonal variation in mean differences from expert rating was similar for both the multiplicative mean and geometric mean, with the largest mean difference resulting from the Spring test. In both cases the deviation from the expert ratings was greater than 0.2 HSI. Ratings from the Summer and Fall tests were fairly accurate using the multiplicative mean. Again, the geometric mean magnified the mean difference for these two tests.

Using subsample data the accuracy of ratings were acceptable for all but the Summer test using the geometric mean. However, the variability of scores was markedly greater than the ratings using ocular data. The variability was so large that the accuracy suggested by the mean deviation from expert rating is questionable.

In another study addressing the accuracy of HEP models in Alaska, Mule' (1982) examined models for beaver (Castor canadensis), caribou (Tarandus rangifer), mink (Mustela vison), common redpoll (Carduelis flammea), green-winged teal (Anas creaca carolinensis), moose and spruce grouse in a variety of habitat types. He also found little agreement between LHSI's and expert ratings and concluded that these models should not be used in their current form.

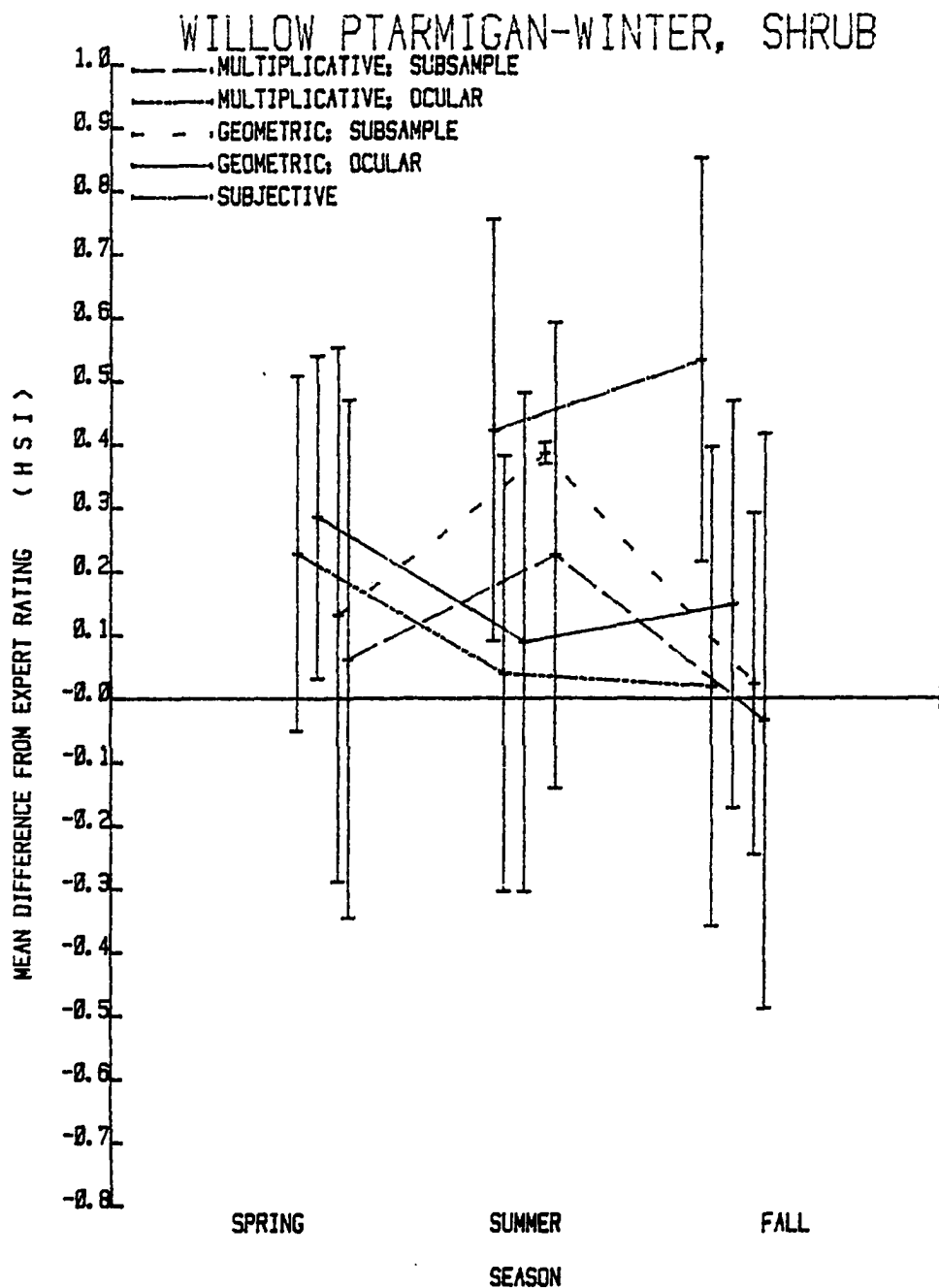


Figure 11. Seasonal means and standard deviations of the difference between expert ratings and LHSI's determined by the willow ptarmigan model in shrub. Results represent LHSI's determined by combinations of ocular and subsample data and calculated by the multiplicative mean and geometric mean. Subjective ratings are also included.

### Subjective ratings

Subjective ratings showed no consistent agreement with expert ratings for any species model in either shrub or mixed forest habitat. Seasonal variation was pronounced and the variability of the ratings often large. It is apparent that the test participants, depending solely on their knowledge of species' habitat needs, were not able to rate habitat accurately.

## Summary and Conclusions

### Nominal data characteristics

Participants accurately and precisely estimated nominal habitat characteristics when the range of possible habitat conditions were presented in an unconfusing manner. If the choices were short, descriptive and sufficiently dissimilar so as to give the evaluator a clear-cut choice of responses, precise and accurate estimation resulted. If the options were ambiguous, or hard to conceptualize, the characteristics were not precisely estimated. I recommend that nominal habitat characteristics be structured in brief, succinct descriptions of habitat conditions. If this is not possible, then the characteristic should be estimated by subsampling.

### Interval data characteristics

In both shrub and mixed forest types, mean ocular estimates of habitat characteristics were greater and more variable than mean subsample estimates. The difference in estimates were significant for all three test dates for eight of the 16 mixed forest parameters and one of eight in shrub. Differences in mean estimates of characteristics were consistently nonsignificant for five of the mixed forest characteristics and one in shrub.

Subsample estimates are usually considered to be more statistically valid than ocular estimates, but estimating characteristics by subsampling took at least three or four times as

long as an ocular inventory of an area. To reduce field time and costs it seems reasonable to prefer ocular estimates if they are not significantly different from subsample estimates. The inventory of habitat characteristics can probably best be accomplished by a combination of ocular and subsample methods.

It is difficult to generalize as to what type of characteristics are better estimated by subsample or ocular inventory. Results from these field tests suggest that in mixed forest, the shrub canopy and ground vegetation characteristics were significantly overestimated by the ocular method and so would be better estimated by subsampling. Ocular and subsample estimates did not statistically differ for tree canopy and for other tree characteristics which were apparent and so could be accurately estimated by the ocular method. Examples of such easily recognizable attributes were the % spruce and birch characteristic (at least 95 % of the trees in the mixed forest plots were either spruce or birch) and the % Populus characteristic (there was a total of one aspen present on the mixed forest plots).

Differences in estimates due to change in seasons was noticeable in the shrub sites. Estimates for six of the eight characteristics were different in Fall. The large number of differences in Fall can be attributed to senescent vegetation. Only one parameter in Summer and two in Spring showed significant differences in estimates. The number of significant differences in estimates stayed fairly constant for the three tests (8, 9, and 10 respectively) in mixed forest.

These results suggest the following:

- 1.) In less stable vegetative communities, such as the shrub sites,



seasonality will have a more profound effect on estimates of habitat characteristics than in the more stable communities, such as mixed forest.

2.) Senescent vegetation appears to magnify the difference between ocular and subsample estimates of habitat characteristics in shrub habitat. Participants were not able to accurately estimate values ocularly in the Fall. This would probably apply to the period before leaf emergence in Spring as well. At Bonanza Creek the optimum period for evaluations was between the third week in May and the third week in September.

#### Limiting Factors

Limiting factors were examined to see how well they agreed with what really was limiting to the evaluation species, as determined from a review of the literature. The spruce grouse model accurately reflected the factors which have been described as limiting to spruce grouse numbers in mixed forest (food in Spring and Summer, cover in Fall) when using the multiplicative mean and subsample data. The snowshoe hare model produced HSI's which were lowest and limiting for food for all seasons. Since food appears to be limiting to hares only in the Summer in mixed forest, only the results from the Summer test were accurate. HSI's for food and cover were limiting and equal for the red squirrel model. All literature sources indicate that food is the limiting factor to red squirrel densities, so in that respect the model was accurate. However, reproduction was also indicated to be

limiting and this is apparently not the case. Food and cover are probably limiting to moose in mixed forest. The model accurately predicted that food was limiting using the multiplicative mean and either ocular or subsample data, but cover was not indicated as being limiting in any season. For moose in shrub habitat, interspersions are probably limiting. The multiplicative mean did produce some LHSI's which were limiting for the interspersions life requisite, but overall interspersions were not indicated as the main limiting factor. Reproduction was the exclusive limiting factor produced by the willow ptarmigan model in shrub habitat. This was an accurate indication.

The multiplicative mean performed much better than the geometric mean in indicating limiting factors. However, it is apparent that the models did not predict the limiting factor for most of the species tested. These results cast serious doubt on the principle of rating a habitat based on the limiting factor concept.

#### Precision of LHSI's

An ANOVA was performed on LHSI's to determine the influence of inventory method and mathematical function used to calculate LHSI's on the habitat ratings.

For those models which showed a significant difference in the variability of LHSI's, subsample data generally produced significantly more precise (less variable) LHSI values than ocular data. The one exception to this trend was the willow ptarmigan model. For those models which showed a significant difference in mean LHSI values, ocular data invariably produced significantly higher ratings

than those generated with subsample data. The variability of ocular LHSI's and subsample LHSI's calculated by the geometric mean were not significantly different for any mixed forest evaluation model.

The geometric mean consistently rendered higher mean LHSI values than the multiplicative mean. Neither the geometric mean or multiplicative mean was found to render exclusively more variable LHSI values.

Subjective ratings tended to be significantly more variable than the LHSI's from all models tested, regardless of how the LHSI's were determined. Subjective ratings overwhelmingly differed from mean LHSI values regardless of how the LHSI's were determined.

#### Accuracy of the LHSI's

Two methods were used to analyze the accuracy of the ratings produced by HEP. The first procedure used a t-test to test the hypothesis that the LHSI's and the expert ratings came from the same population. Results from this test indicated the models did not produce accurate ratings. LHSI's generated with ocular data were consistently significantly different from the expert rating for all mixed forest models except the red squirrel model using the geometric mean. Agreement with expert ratings was much better for shrub habitat models.

With subsample data, accuracy improved slightly with the mixed forest models, but most models did not produce ratings which agreed with the experts. Accuracy in the shrub habitat was worse with subsample data.

The willow ptarmigan model was the only model in either habitat which was consistently in agreement with the expert ratings. This agreement has been shown to be the result of one habitat characteristic (elevation) which had an HSI of 0.0.

Subjective ratings were in better general agreement than LHSI's generated with either ocular or subsample data. Subjective ratings for willow ptarmigan and snowshoe hare consistently agreed with expert ratings. Subjective ratings for all species in May did not significantly differ from the opinion of species authorities.

Judging the accuracy of HEP in this manner one has to conclude that the system has serious problems with most species models.

The second method used to judge accuracy examined the mean absolute difference between LHSI's and expert ratings. Looking at the ratings from this perspective, both the moose and moose-winter models produced very accurate and precise habitat ratings for mixed forest. These were LHSI's generated by the multiplicative mean and using either ocular or subsample data. The high degree of agreement is probably an artifact of the poor habitat and large number of variables involved in the moose model rather than an indication that the model is able to accurately rate moose habitat. The willow ptarmigan model in shrub showed complete agreement with the expert rating as discussed previously. No other model came close to this degree of consistent accuracy and precision. However, most models were able to produce LHSI's which were more accurate, although less precise, than subjective ratings.

### Applicability of HEP

The concepts upon which HEP is based must be reassessed. A major weak point with the basic theory of HEP is the idea of a limiting factor, or a law of the minimum (Pianka 1974). Kling (1980) also points to this principle as one of several "core concepts" of HEP which have not been proven. As applied in HEP, the principle maintains that populations are regulated by one or more requisites (e.g. water, food, reproduction) in short supply, while other resources in plentiful supply are not fully exploited. But, limiting factors are not always clearcut. Often, several factors interact to become limiting, and a change in any of them can lead to a new equilibrium (Pianka 1974).

As an example of such a compensatory reaction, take a summer population of spruce grouse in mixed forest. Blueberries and bearberries are very abundant and the food requisite is assigned an HSI of 1.0. Cover, on the other hand, is sparse and receives a rating of 0.1 HSI. Other requisites are rated in between these extremes. Cover becomes the limiting factor and the habitat is assigned an HSI of 0.1, accordingly. This rating is not really indicative of the true habitat quality. Lack of cover means that grouse will be subject to a high level of predation, but a readily available, abundant and rich food source is probably going to attract a large number of birds which can stand increased predation and still maintain a high population. Actual habitat usage will probably be greater than if the cover value were higher and the food value lower. This would not be

reflected in the rating assigned to the habitat. Whether the limiting factor concept is applicable in other situations remains to be proven.

Probably the most troubling aspect of HEP is the lack of attention paid to the population of a species in an area being evaluated. Effort is concentrated on inventorying habitats instead of gaining an understanding of the population which is likely to be adversely effected by development. The extent to which a population utilizes an area is not considered in arriving at a habitat rating.

According to the Ecological Services Manual 101, HSI's reflect the potential carrying capacity of Habitat (USFWS 1980a). The manual states:

"Carrying capacity estimates based on the resource inventory approach will nearly always be estimates of potential, because the limiting effects of other species (competitors and predators) are difficult to explicitly include in the calculations."

and

"A habitat approach may not include all of the many environmental or behavioral variables that often limit populations below the habitat potential."

I find this rationale specious. First, it admits that there are drawbacks to the HEP approach of estimating carrying capacity, since many important factors cannot be considered in deriving a habitat rating. Then, having cursorily mentioned these drawbacks, it proceeds to ignore them.

Secondly, and more important, the logic ignores the major objective of the entire habitat assessment and mitigation operation.

That objective is to preserve habitat that will ultimately produce wildlife. The extent to which a population utilizes an area is not considered in arriving at a habitat rating. I think it is essential to have some understanding of the behavior, reproductive dynamics, degree of habitat utilization and seasonal movements of a wildlife population in a large area which includes the proposed development site before the impact of such a development can be accurately assessed.

Consider a population residing in an area surrounding a proposed development site. In section A of the range the population is abundant; in section B the population is sparse. For whatever reasons (e.g. predation, competition, epizootic disease, excessive departure from normal weather patterns, overhunting) section B is not frequented or utilized nearly as much as section A. Although there might not be obvious differences in the structure or physiognomy of the vegetative communities of A and B, there is a difference in the amount of habitat utilization between the two sections. The impact of a development on the population will be different depending upon where the project is located. In section A the development would have disastrous effects, displacing a segment of the population from obviously prime habitat. In section B the effect would be negligible, since the population does not utilize the area to a great extent. But because of the homogeneous nature of the habitat in the two sections, HEP would have assigned similar ratings (although misleading in terms of habitat utilization) to both sections A and B.

Wildlife population studies are time consuming and costly, but I

believe that they are essential in assessments of the importance of habitats and HEP is not a viable alternative. This study and others (Clawson 1980; Kling 1980; Mule' 1982) have shown that most HEP models are not able to accurately assign a rating of habitat quality, and most require substantial revision before they are capable of doing so. Several recent studies (Whelan et al 1979; Clawson 1980; Kling 1980; Darrow et al 1981) compared HEP ratings with population levels and/or habitat utilization and found little correlation. In lieu of an adequate population study in a proposed development area, I believe the opinion of experienced species specialists should be considered along with or instead of HEP assessments.

The species models tested in this study were not consistently accurate in evaluating the importance of habitat to selected species of wildlife. I agree with Mule's (1982) assessment of the shortcomings of HEP. He discussed several aspects of HEP which need to be addressed before the system can effectively be used in habitat assessments in Alaska. Mule' sees the following problems with HEP: There is not adequate data on species habitat requirements; models were written by technicians who did not have an extensive knowledge of the species with which they were dealing; the HEP approach may not be appropriate to deal with carnivores and large, mobile, herbivorous habitat generalists (e.g. moose and caribou); HEP fails to treat the problem of competitive-interaction of species; and HEP does not adequately consider interspersions of habitat types. An adequate data base on habitat requirements of most Alaskan species does not yet



exist to make models feasible. Thus, studies to determine the habitat needs of key wildlife species must be conducted.

### References Cited

- Brink, Charles Holden. 1964. Spruce seed as a food of the squirrels Tamiasciurus hudsonicus and Glaucomys sabrinus in interior Alaska. M.S. Thesis, Univ of Alaska. College. 73 pp.
- and F.C. Dean. 1966. Spruce seed as a food of red squirrels and flying squirrels in interior Alaska. J. Wildl Mgmt. 30(3):503-512.
- Bailey, R. G. 1976. Ecoregions of the United States. U.S.D.A. forest Service, Ogden, Utah. Map.
- Baskett, Thomas S., D.A. Darrow, D.L. Hallett, M.J. Armbruster, J.H. Ellis, B.F. Sparrowe, and P.A. Korte. 1980. A handbook for terrestrial habitat evaluation in central Missouri. U.S.F.W.S. Resource Publication 133. Washington, D.C. 155 pp.
- Brown, Morton B. and Alan B. Forsythe. 1974. Robust tests for the equality of variances. J. of Am. Stat Assoc. Vol. 69 346. pp. 364-367.
- Clawson, M.E. 1980. Evaluating handbooks for small mammals and herpetofaunal habitat assessment. M.S. Thesis. University of Missouri, Columbia. 228 pp.
- Conroy, Michael J., Leslie W. Geysel, and Glenn R. Dudderar. 1979. Habitat components of clear-cut areas for snowshoe hares in Michigan. J. Wildl. Mgmt. 43(3):680-690.
- Cottam, G., and J. T. Curtiss. 1956. The use of distance measures in phytosociological sampling. Ecology 36: 451-460.
- Daniel, Clarence and Robert Lamaire. 1974. Evaluating effects of water resource developments on wildlife habitat. Wild. Soc. Bull. Vol 2(3):114-118.
- Darrow, D. A., T. S. Baskett and J. N. Burroughs. 1981. Habitat quality scores related to indicators of abundance of white-tailed deer, eastern wild turkeys, eastern cottontail and bobwhites. Report to Habitat Evaluation Procedures Group, U.S.F.W.S. Fort Collins, Co. 77 pp.
- Davis, J. C. 1973. Statistics and data analysis in geology. John Wiley and Sons, Inc. N. Y. 550 pp.

- Dice, Lee Raymond. 1921. Notes on the mammals of interior Alaska. J Mamm. 2:20-28.
- Dyrness, C. T. and L. A. Viereck. 1980. A preliminary classification system for vegetation of Alaska. General Technical Report PNW-106. Forest Service. U.S.D.A. 38 pp.
- Ellis, J. A. 1978. Results of testing four methods of habitat evaluation. Report to the Project Impact Evaluation Team. Fort Collins, Co. 92 pp.
- \_\_\_\_\_, J.N. Burroughs, M.J. Armbruster, D.L. Hallet, P.A. Korte, and T.S. Baskett. 1979. Appraising four field methods of terrestrial habitat evaluation. Trans. 44th N. Am. Wildl. Nat. Resour Conf. 44:369-379.
- Ellison, Laurence. 1971. Territoriality in Alaskan spruce grouse. Auk 88(3):652-664.
- Flood, B.S., M.E. Sangster, R.D. Sparrowe, and T.S. Baskett. 1977. A handbook for habitat evaluation procedures. U.S.F.W.S. Resource Publ. 132. 77 pp.
- Flood, Bettina Suzanne. 1977. Development and testing of a handbook for habitat evaluation procedures. M.S. Thesis. University of Missouri, Columbia. 149 pp.
- Holmberg, Nevin D. 1977. The habitat evaluation procedures: a test of replicability. Ecological Services memorandum report no. 1. U.S.F.W.S. Washington, D.C.
- Johnsgard, Paul A. 1973. Grouse and quails of North America. University of Nebraska, Lincoln. 553 pp.
- Kling, C.L. 1980. Pattern recognition for habitat evaluation. M.S. Thesis. Colorado State University Fort Collins. 244 pp.
- Konkel, Gregory W., (ed.) 1980. Terrestrial habitat evaluation criteria handbook-Alaska. U.S.F.W.S. Anchorage, Ak.
- Layne, James N. 1954. The biology of the red squirrel (Tamiasciurus hudsonicus) in central New York. Can. Field-Nat. 24:227-267.
- Levene, H. 1960. Robust test of equality of variance in I. Olkin, ed., Contributions to Probability and Statistics. Palo Alto, Calif, Stanford University Press. pp 278-292.
- Mule', R. S. 1982. An assessment of a wildlife habitat

- evaluation methodology for Alaska. M. S. Thesis. University of Alaska. College. 215 pp.
- Murie, Olaus J. 1927. The Alaska red squirrel providing for winter. J Mamm. 8:37-41.
- Ohmann, L. F. and R. R. Ream. 1971. Wilderness ecology: A method of sampling and summarizing data for plant community classification. U.S.D.A. Forest Service Research Paper NC-49. St. Paul. 14 pp.
- Pianka, Eric R. 1974. Evolutionary ecology. Harper and Row. N.Y. 356 pp.
- Smith, M.C. 1966 Red squirrel (Tamiasciurus hudsonicus) ecology during spruce cone failure in Alaska. M.S. Thesis, University of Alaska, College. 68 pp.
- Sokal, R. R. and F. S. Rohlf. 1969. Biometry. W. H. Freeman Co. San Francisco. 776 pp.
- Sparrow, Rollin D. and Bettina Flood Sparrow. 1977. Use of critical parameters for evaluating wildlife habitat. Typewritten copy. Mo. Coop. Wildl. Res Unit, Columbia.
- Whelan, J.B. and A.R. Tipton, J.F. Williamson, P.R. Johnson, J.P. McClure N.D. Cost. 1979. A comparison of three systems for evaluating forest wildlife habitat. Trans. N. Am. Wildl. and Nat. Res. Conf. 44:392-403.
- Wolff, J.O. 1977. Habitat utilization of snowshoe hares (Lepus americanus) in interior Alaska. Ph. D. dissertation, University of California, Berkeley. 137 pp.
- \_\_\_\_\_, 1978. Food habits of snowshoe hares in interior Alaska. J Wildl. Mgmt. 42(1):148-153.
- U.S. Fish and Wildlife Service. 1976. Habitat Evaluation Procedures. Division of Ecological Services. Washington, D.C. 30 pp.
- \_\_\_\_\_. 1980. Ecological services manual. Part 101 - Habitat as a basis for environmental assessment. Washington, D.C. 34 pp.
- \_\_\_\_\_. 1980. Ecological Services Manual. Part 102 - Habitat Evaluation Procedures (HEP). Washington, D.C. 145 pp.
- \_\_\_\_\_. 1981. Ecological Services Manual. Part 103 - Standards for the development of Habitat Suitability Index Models. Washington, D.C. 202 pp.

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## **Appendices**

Appendix 1. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for mixed forest habitat characteristics inventoried in Spring.

	Mean	SD	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
			SE	SE			SD	SE	
% Spruce and birch	86.90	27.26	8.22	0.31		98.64	0.81	0.24	0.01
% Populus	0.00	0.00	0.00			0.00	0.00	0.00	
% Spruce	35.81	7.24	2.18	0.20		21.54	2.77	0.84	0.13
% Coniferous	35.81	7.24	2.18	0.20		21.54	2.77	0.84	0.13
% Black spruce	0.45	1.51	0.46	3.35		0.18	0.60	0.18	3.35
% Tree canopy	50.45	21.50	6.48	0.43		40.45	21.50	6.48	0.25
Trees/acre	425.00	487.37	135.17	1.15		130.27	28.55	8.61	0.22
Height of trees	60.54	14.71	4.08	0.24		44.73	3.66	1.10	0.08
% Shrub canopy	35.92	20.34	5.64	0.57		14.73	3.00	0.90	0.20
Shrub height	11.23	2.59	0.72	0.23		10.45	1.44	0.43	0.14
% Herbaceous ground cover	16.08	14.90	4.13	0.93		8.45	7.98	2.40	0.94
% Berry-producing plants	3.31	2.78	0.77	0.84		2.09	1.76	0.53	0.84
Height of ground vegetation	2.45	0.91	0.25	2.41		0.38	1.81	0.55	0.74
% Vegetative ground cover	45.39	22.03	6.11	0.49		8.09	8.09	2.44	1.00

Appendix 2. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for mixed forest habitat characteristics inventoried in Summer.

	Mean	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
		SD	SE			SD	SE	
% Spruce and birch	93.67	6.12	2.50	0.07	98.64	0.81	0.24	0.01
% Populus	0.00	0.00	0.00		0.00	0.00	0.00	
% Spruce	40.00	8.37	3.42	0.21	21.54	2.77	0.84	0.13
% Coniferous	40.00	8.37	3.42	0.21	21.54	2.77	0.84	0.13
% Black spruce	0.00	0.00	0.00		0.18	0.60	0.18	3.35
% Tree canopy	55.00	16.73	6.83	0.30	40.00	4.98	2.03	0.12
Trees/acre	327.50	266.79	108.92	0.81	130.27	28.55	8.61	0.22
Height of trees	66.50	27.27	11.13	0.41	44.73	3.66	1.10	0.08
% Shrub canopy	48.33	7.53	3.07	0.16	27.00	13.39	5.47	0.50
Shrub height	12.50	4.18	1.71	0.33	10.45	1.44	0.43	0.14
% Herbaceous ground cover	43.33	25.03	10.22	0.58	15.83	9.62	3.93	0.61
% Berry-producing plants	8.00	7.01	2.86	0.88	2.33	1.51	0.62	0.65
Height of ground vegetation	2.81	1.17	0.48	0.41	0.97	0.16	0.07	0.17
% Vegetative ground cover	50.83	20.60	8.41	0.41	38.00	9.90	4.04	0.26



Appendix 3. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for mixed forest habitat characteristics inventoried in Fall.

	Mean	SD	<u>Ocular</u> SE	CV	Mean	<u>Subsample</u> SD	SE	CV
% Spruce and birch	91.73	11.53	3.48	0.13	98.64	0.81	0.24	0.01
% Populus	4.18	11.97	3.61	2.86	0.00	0.00	0.00	
% Spruce	47.82	10.02	3.02	0.21	21.54	2.77	0.84	0.13
% Black spruce	1.45	4.50	1.36	3.10	0.18	0.60	0.18	3.35
% Tree canopy	38.64	19.38	5.84	0.50	21.18	10.34	3.11	0.49
Trees/acre	336.00	231.26	69.73	0.69	130.27	28.55	8.61	0.22
Height of trees	68.18	25.72	7.75	0.38	44.73	3.66	1.10	0.08
% Shrub canopy	22.18	11.59	3.50	0.52	12.82	9.86	2.97	0.77
Shrub height	11.73	2.83	0.85	0.24	10.45	1.44	0.43	0.14
% Herbaceous ground cover	30.91	33.38	10.06	1.08	6.09	4.99	1.50	0.82
% Berry-producing plants	5.46	7.02	2.12	1.29	4.09	4.23	1.27	1.03
Height of ground vegetation	2.27	1.42	0.42	0.62	0.50	0.28	0.08	0.56
% Vegetative ground cover	53.64	26.28	7.92	0.49	26.91	8.83	2.66	0.33

Appendix 4. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for mixed forest habitat characteristics inventoried in all test dates combined.

	Mean	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
		SD	SE			SD	SE	
% Spruce and birch	93.67	8.43	1.58	0.09	98.63	0.81	0.24	0.01
% Populus	1.53	7.71	1.34	4.78	0.00	0.00	0.00	
% Spruce	40.80	9.79	1.81	0.24	21.30	2.98	1.06	0.14
% Black spruce	0.64	2.84	0.54	4.44	0.30	0.85	0.31	2.83
% Tree canopy	46.86	20.21	3.19	0.43	32.78	13.16	2.48	0.40
Tress/acre	384.21	372.67	70.42	0.97	130.70	30.06	5.68	0.23
Height of trees	64.53	21.29	3.91	0.33	44.54	4.45	1.52	0.10
% Shrub canopy	35.07	17.40	3.29	0.50	16.61	10.19	1.93	0.61
Shrub height	11.64	2.96	0.56	0.25	11.07	2.04	0.39	0.18
% Herbaceous ground cover	28.71	26.51	5.01	0.92	8.96	8.04	1.52	0.90
% Berry-producing plants	5.29	5.77	1.09	1.09	2.71	2.85	0.54	1.05
Height of ground cover	1.84	1.31	2.48	0.71	0.50	0.35	0.07	0.70
% Vegetative ground cover	49.50	22.77	4.19	0.46	25.28	10.55	2.11	0.42

Appendix 5. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for shrub habitat characteristics inventoried in Spring.

	Mean	SD	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
			SE	SE			SD	SE	
% Alder	13.42	7.93	2.29		0.59	5.30	1.40	0.04	0.26
% Willow	67.92	19.36	5.59		0.29	57.50	13.40	4.72	0.23
% Shrub canopy	39.58	23.11	6.67		0.58	17.10	6.23	1.98	0.36
Shrub height	10.75	3.82	1.10		0.36	11.24	11.04	3.90	0.98
% Forbs	4.90	7.23	2.29		1.48	0.48	0.32	0.10	0.38
% Bryophytes and graminiforms	16.70	30.95	9.97		1.85	5.09	1.94	0.61	0.38
Height of ground vegetation	0.46	0.37	0.12		0.80	0.12	0.13	0.04	1.08

Appendix 6. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for shrub habitat characteristics inventoried in Summer.

	Mean	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
		SD	SE			SD	SE	
% Alder	16.67	9.85	4.02	0.59	5.30	1.40	0.04	0.26
% Willow	60.67	27.29	11.14	0.45	57.50	13.40	4.72	0.23
% Shrub canopy	50.83	22.45	9.17	0.44	36.67	9.65	3.90	0.26
Shrub height	11.33	4.18	1.71	0.37	11.24	11.04	3.90	0.98
% Forbs	67.67	31.95	13.04	0.47	66.00	1.26	0.51	0.02
% Bryophytes and graminiforms	10.83	14.63	5.97	1.35	8.17	6.21	2.54	0.76
Height of ground vegetation	2.42	1.02	0.42	0.41	1.35	0.19	0.08	0.14

Appendix 7. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for shrub habitat characteristics inventoried in Fall.

	Mean	SD	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
			SE				SD	SE	
% Alder	8.46	7.99	2.41	0.95	5.30	1.40	0.04	0.26	
% Willow	74.09	19.94	5.41	0.28	57.50	13.40	4.72	0.23	
% Shrub canopy	32.00	19.41	5.85	0.61	12.36	8.92	2.69	0.72	
Shrub height	11.54	2.30	0.69	0.20	11.24	11.04	3.90	0.98	
% Forbs	10.40	28.08	8.88	2.70	0.77	1.14	0.34	1.48	
% Bryophytes and graminiforms	44.70	32.52	10.28	0.73	7.86	4.04	1.22	0.51	
Height of ground vegetation	1.20	0.89	0.28	0.74	1.06	0.94	0.28	0.89	

Appendix 8. Mean, standard deviation, standard error of the mean and coefficient of variation for ocular and subsample data for shrub habitat characteristics inventoried in all tests combined.

	Mean	SD	<u>Ocular</u>		CV	Mean	<u>Subsample</u>		CV
			SE				SD	SE	
% Alder	12.33	8.81	1.69	0.71	5.30	1.40	0.00	0.26	
% Willow	67.19	24.34	4.66	0.36	57.50	13.40	4.72	0.23	
% Shrub canopy	40.26	22.23	4.28	0.55	19.52	12.38	2.38	0.63	
Shrub height	10.67	3.49	0.67	0.33	11.24	11.04	3.90	0.98	
% Forbs	18.44	30.76	5.92	1.67	15.29	27.64	5.32	1.81	
% Bryophytes and graminiforms	29.63	31.83	6.13	1.07	6.83	4.18	0.80	0.61	
Height of ground vegetation	1.96	4.13	0.79	2.11	0.78	0.79	0.15	1.01	